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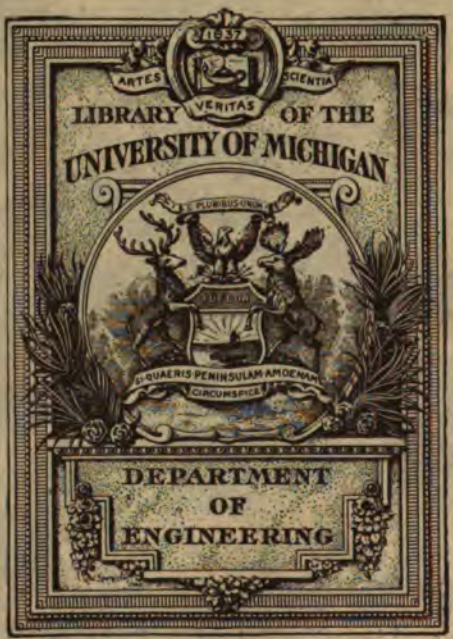
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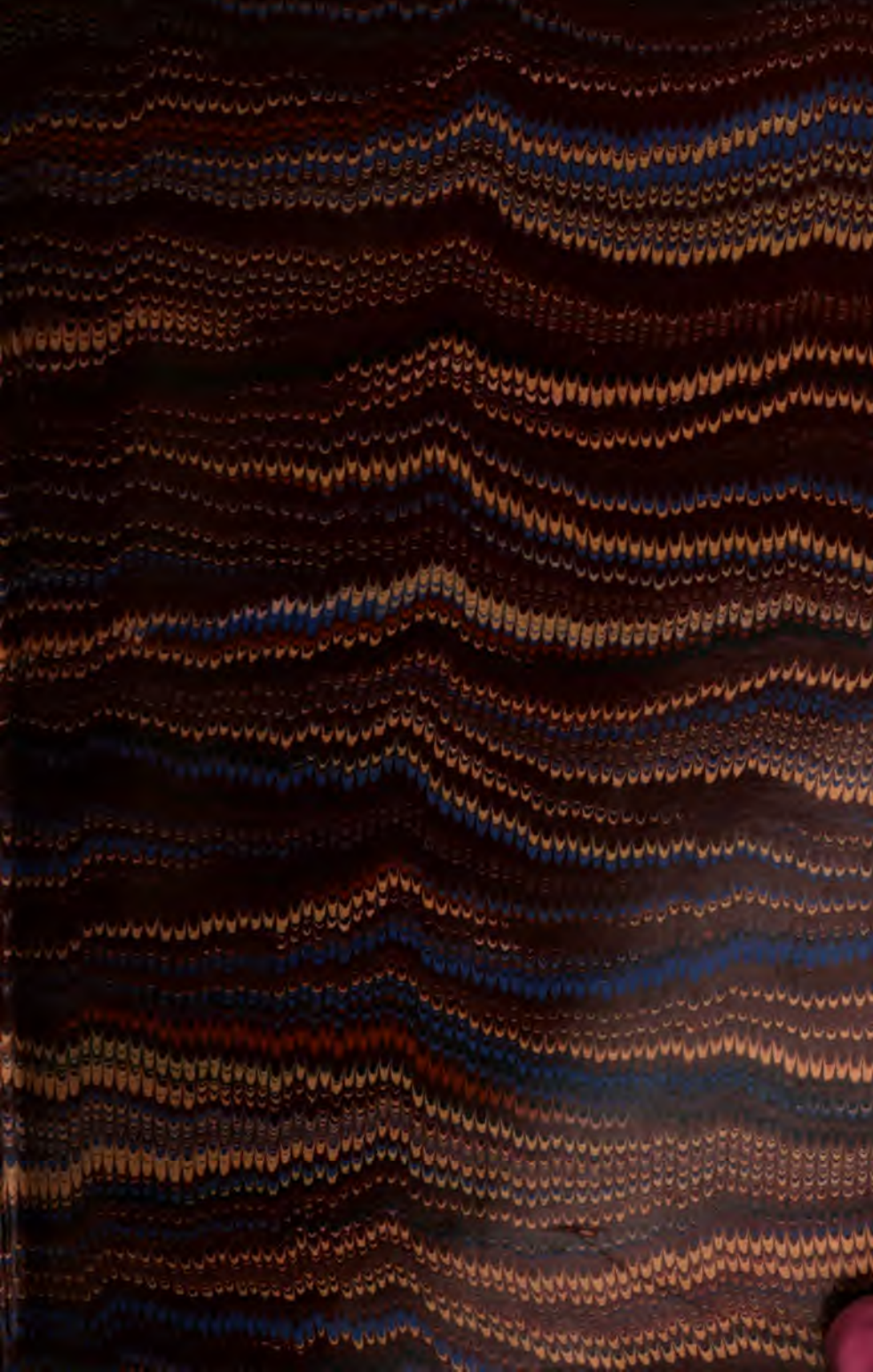

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INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1865.

PUBLISHED BY THE INSTITUTION,
31 NEWHALL STREET, BIRMINGHAM.

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WITH YEAR OF ELECTION.

1865.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Worcester Engine Works, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1865. Alleyne, John Gay Newton, Butterley Iron Works, Alfreton.
1859. Alton, George, Midland Road, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, Kent, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Iron Works, near Chesterfield.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1863. Armstrong, John, Timber Works, 20 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1865. Barclay, William, Locomotive Superintendent, Inverness and Perth Railway, Inverness.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Machine Works, Bolton.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.
1865. Bass, William, Solway Screw Bolt and Rivet Works, Workington.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, 27 Victoria Street, Westminster, S.W.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby.
1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1865. Bell, John, Liver Foundry, Salford, Manchester.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1865. Bennett, Henry, Wombridge Iron Works, near Wellington, Shropshire.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1865. Benson, George Henry, Stocksbridge Works, Deepcar, near Sheffield.
1865. Benson, Martin, 14 Hinde Street, Manchester Square, London, W.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1863. Birckel, John James, Regent's Canal Iron Works, Eagle Wharf Road, London, N.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Dudley.
1865. Bladen, Charles, Jarrow Iron Works, near Gateshead.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.
1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.
1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)
1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.
1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1865. Brock, Walter, Vulcan Foundry, Glasgow.
1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)
1865. Brown, George, Rotherham Iron Works, Rotherham.
1863. Brown, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel and Iron Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.
1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India.
1859. Butler, John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.

1864. Carrington, William Thomas, 19 Great George Street, Westminster, S.W.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1865. Cartwright, John, New Bond Street Iron Works, Coventry Road, Birmingham.
1857. Chrimes, Richard, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Knott Mill Iron Works, Manchester.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1847. Clift, John Edward, Prospect Hill, Redditch.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1865. Coates, Victor, Lagan Iron Works, Belfast.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, care of Hugh Hornby, Sandown, Wavertree, Liverpool.
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 3 East Parade, Sheffield.
1863. Craig, Andrew, Rock Ferry, Birkenhead.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.
1858. Cubitt, Charles, 8 Great George Street, Westminster, S.W.
1865. Curtis, Matthew, Phœnix Foundry, Chapel Street, Manchester.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Newport, Monmouthshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
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1865. Davies, Benjamin, Huyton Bleach Works, near Chorley.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1864. Dewhurst, John, Wadsley Bridge Iron and Steel Works, near Sheffield.
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1865. Domville, Charles Kelloch, Resident Engineer and Locomotive Superintendent, Belfast and County Down Railway, Belfast.
1865. Douglas, Charles P., Consett Iron Works, near Gateshead.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
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1847. Dubs, Henry, Glasgow Locomotive Works, Glasgow.
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1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1864. Dunn, Thomas Edward, Jumna Bridge, East Indian Railway, Allahabad, India: (or care of R. Dunn, Howick, near Alnwick).
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1865. Elliot, Walter, Civil Engineer to the Colonial Government, Gibraltar.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1858. England, George, Hatcham Iron Works, London, S.E.

1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1864. Etienne, Antonin, Engineer, Cordova and Seville Railway, Seville, Spain.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1865. Faviell, Samuel Clough, Clarence Iron Works, Leeds.
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1854. Fernie, John, Clarence Iron Works, Leeds.
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1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 5 South Parade, Leeds.
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1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
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1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
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1865. Gainsford, William Dunn, Sheffield Coal Co., Sheffield.
1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1865. Gibbs, William, Deepfields Iron Works, near Wolverhampton.
1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.
1865. Gray, John McFarlane, Vauxhall Foundry, Liverpool.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
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1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.
1865. Greig, David, Steam Plough Works, Leeds.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.
1865. Grimshaw, William Dakin, Harris Buildings, Icknield Port Road, Birmingham.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1864. Halkett, John Craigie, Cramond Iron Works, Edinburgh.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1857. Hall, William, Ashted Varnish and Colour Works, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
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1856. Harrison, George, Canada Works, Birkenhead.
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1865. Harrison, William Arthur, Cambridge Street Works, Manchester.
1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering, Yorkshire.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow. (*Life Member.*)
1861. Hawkins, William Bailey, 24 Budge Row, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.

1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Assistant Engineer, Ceylon Railway, Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham.)
1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1865. Heptinstall, John, Rotherham Iron Works, Rotherham.
1865. Hetherington, John Muir, Vulcan Iron Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
1864. Hide, Thomas C., 46 Fenchurch Street, London, E.C.
1863. Hind, Roger, Scotland Bank Iron Works, Warrington.
1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Gorton Foundry, Manchester.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesbrough.
1856. Hopkinson, John, London Road Iron Works, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1864. Howard, Eliot, 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1862. Huber, Peter Emile, Iron Works, near Zurich, Switzerland.
1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1847. Humphrys, Edward, Deptford Pier, London, S.E.
1859. Hunt, James P., Gospel Oak Iron Works, Tipton.
1856. Hunt, Thomas, North of England Railway Carriage Works, West Strand, Preston.
1864. Hutchinson, Edward, Skerne Iron Works, Darlington.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.
1865. Hyde, Capt. Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, Camberwell, London, S.)

1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1865. Jackson, John, Harbour of Refuge Works, Alderney.
1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.
1865. Jarvis, Edward George, Railway Saw Mills, Gloucester.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1861. Jones, Alfred, Ettingshall Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesbrough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
1848. Kirkham, John, 109 Euston Road, London, N.W.

1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1863. Knight, Thomas, 130 Bradford Street, Birmingham.

1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 11 Park Grove, Bromley, Kent, S.E.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Junction Works, Miles Platting, Manchester.
1865. Leigh, Frederick Allen, Junction Works, Miles Platting, Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.

1861. Low, George, St. Peter's Iron Works, Ipswich.
1865. Lundh, Sverier Hakon, 36 Regent Square, London, W.C.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, care of Charles Lee, 23 Allen Street, Hercules Buildings, Lambeth, London, S.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Cyclops Steel and Iron Works, Sheffield.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1865. Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.
1862. Marshall, James, 4 Gloucester Terrace, Rye Hill, Newcastle-on-Tyne.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 13 High Street, Stourbridge.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.
1857. Masselin, Armand, Folembray, Aisne, France.
1853. Mathews, William, The Leasowes, near Birmingham.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1853. Maudslay, Henry, Cheltenham Place, Lambeth, London, S. (*Life Member.*)
1864. Maudslay, Thomas Henry, Cheltenham Place, Lambeth, London, S.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Engineer and Shipbuilder, Rio de Janeiro: Mayfield, King Street, Oxton, Birkenhead.
1859. Maylor, William, East Indian Iron Company, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)

1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1864. McEwen, Lawrence Thomson, Ormesby Iron Works, Middlesbrough.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Worcester Engine Works, Worcester.
1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Birkenhead.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1865. Morton, Robert, Brass Works, Stockton-on-Tees.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, Britannia Works, Sherborne Street, Strangeways, Manchester.
1857. Munts, George Frederick, French Walls, near Birmingham.
1865. Murdock, William Mallabey, Eagle Foundry, Northampton.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.

1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Anthony Nichol, 19 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid, Spain.
1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
1848. Penn, John, The Cedars, Lee, Kent, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Francis Street, Regent Square, London, W.C.
1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., 45 Leamington Road Villas, Bayswater, London, W.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.
1859. Platt, John, Hartford Iron Works, Oldham.
1862. Player, John, Norton, near Stockton-on-Tees.
1861. Plum, Thomas William, Ravensdale Iron Works, Tunstall, near Stoke-upon-Trent.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1864. Potts, Benjamin Langford Foster, 150 Camberwell Grove, London, S.

1851. Potts, John Thorpe, 3 East Parade, Sheffield.
1865. Pratchitt, William, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, East Howden, near Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1863. Richards, Edwin, Nantyglo Iron Works, near Newport, Monmouthshire.
1865. Richards, Job, Rabone Bridge Iron Works, Smethwick, near Birmingham.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Engineer, Lyttelton, New Zealand.
1865. Richardson, John, Engineer to the Corporation and the Water Works, Gloucester.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1865. Rideal, Samuel, 18 Hopwood Avenue, Manchester.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1865. Robinson, John, Railway Works, Rochdale.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Boston.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester
1860. Rumble, Thomas William, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1863. Ryder, William, Bark Street, Bolton.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1857. Samuelson, Martin, Scott Street Foundry, Hull.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.
1864. Sanderson, John, Locomotive Superintendent, Whitehaven Cleator and Egremont Railway, Moor Row, near Whitehaven.
1860. Schneider, Henry William, M.P., Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of Joseph Reid, 49 Arundel Square, London, N.)
1864. Seddon, John, 31 King Street, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, United States.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, 13 Bennett's Hill, Birmingham.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1854. Smith, George, Wellington Road, Dudley.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1860. Smith, Richard, Berry Hill, Lichfield.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1863. Somerville, Wallace Cochrane, London Works, Birmingham.
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1859. Spencer, John Frederick, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1864. Stokes, James Folliott, Meole Brace, Shrewsbury.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, Highland Railway, Inverness.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1864. Thomas, Thomas, Clyde House, Canton, Cardiff.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.

1852. Thomson, George, Crookhay Iron Works, Westbromwich.

1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1865. Tickle, John, Providence Engine Works, Westbromwich.

1862. Tijou, William, 9 Great George Street, Westminster, S.W.

1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)

1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.

1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.

1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.

1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.

1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1863. Townsend, William, West Orchard, Coventry.

1865. Trow, John James, Messrs. William Trow and Sons, Wednesbury.

1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.

1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.

1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1863. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.

1865. Usher, George Moon, Beverley Iron Works, Beverley.

1862. Vavasseur, Josiah, Bear Lane, Southwark Street, London, S.E.

1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.

1865. Vickers, Albert, Don Steel Works, Sheffield.

1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.

1856. Waddington, Thomas, New Dock Iron Works, Leeds.

1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.

1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.

1861. Walker, John G., Netherton Iron Works, near Dudley.

1847. Walker, Thomas, Patent Shaft Works, Wednesbury.

1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Company, Liverpool.

1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.

1865. Walpole, Thomas, Port of Dublin Ship Yard, Dublin.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.

1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Burton Iron Works, Burton-on-Trent.

1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.

1862. Webb, Francis William, London and North Western Railway, Locomotive Department, Crewe.

1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.

1860. Weild, William, Queen's Chambers, Market Street, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1847. Whitworth, Joseph, Chorlton Street, Manchester.

1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay: 32 Cambridge Street, Eccleston Square, London, S.W.

1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford Yorkshire.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)

1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, Stocksbridge Works, Deepcar, near Sheffield.
1856. Wilson, Edward, Great Western Railway, Worcester.
1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.
1865. Wilson, James Edwards, Engineer, Indian Branch Railways; 1 Westminster Buildings, Westminster, S.W.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Vauxhall Foundry, Liverpool.
1853. Wymer, Francis W., Superintending Engineer, Tyne Steam Shipping Company, Quayside, Newcastle-on-Tyne.

1861. Yule, William, Nevesky Foundry, St. Petersburg, Russia.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Museum Building, Trinity College, Dublin.
1847. Fairbairn, William, LL.D., The Polygon, Ardwick, Manchester.

HONORARY MEMBERS.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1848. Branson, George, Belmont Row, Birmingham.
1864. Branson, Joseph W., Belmont Row, Birmingham.
1863. Brockbank, William, 37 Princess Street, Manchester.

1863. Butler, William, 15 Bilbao Street, Cadiz, Spain.
1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.
1848. Crosby, Samuel, Leek Street, Birmingham.
1863. Fairbairn, John, Farnley Iron Works, Leeds.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1863. Hackney, William, 3 Great George Street, Westminster, S.W.
1865. Hall, John, Lancashire Steel Co., Gorton Lane, Manchester.
1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.
1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. Lawton, Benjamin C., Benwell Grange, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1864. Peyton, Abel, Oakhurst, Church Road, Edgbaston, Birmingham.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1859. Sherriff, Alexander Clunes, Great Western Railway, Worcester.
1863. Storey, Thomas R., 17 Gracechurch Street, London, E.C.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Member.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1865. Warden, Thomas, Lionel Street, Birmingham.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1862. Whitehead, William, Don Steel Works, Sheffield.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1865. Hewett, Edward Edwards, Midland Railway, Locomotive Department, Derby.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.

PROCEEDINGS.

26 JANUARY, 1865.

The EIGHTEENTH ANNIVERSARY MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 26th January, 1865; ROBERT NAPIER, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1865.

The Council have great pleasure, on this the Eighteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1864 shows a balance in the Treasurer's hands of £2901 19*s.* 5*d.* after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1864, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the last year; the total number of Members of all classes for the year being 572, of whom 12 are Life Members, 29 are Honorary Members, and 2 are Graduates, being an effective increase of 32 during the year.

The following deceases of Members of the Institution have occurred during the last year 1864:—

JAMES ALLEN, ...	Manchester.
WILLIAM HARRISON BARWELL, .	Northampton.
WILLIAM STEEL BROWN, . . .	Glasgow.
JOHN FOWLER, ...	Leeds.
JOHN HEDLEY, ...	Newcastle-on-Tyne.
EDWIN MARSHALL, . . .	Birmingham.
GEORGE MACKEY MILLER, . .	Dublin.
WILLIAM SIMPSON, . . .	London.
CHARLES LINGARD STOKES, . .	London.
WILLIAM HENRY WOODHOUSE, .	London.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Treatise on Practical Hydraulics, by Samuel Downing; from the author.

Description of Haarlem Lake Drainage, by Samuel Downing; from the author.

The Exhibited Machinery of 1862, by D. K. Clark; from the President.

On the Combustion of Coal, by C. Wye Williams; from Mr. Zerah Colburn.

Papers on Iron, and on the effect of Impact upon Wrought Iron Girders, by William Fairbairn; from the author.

On the Rolling &c. of Ships, by W. J. Macquorn Rankine; from the author.

Proceedings of the Institution of Civil Engineers; from the Institution.

Report of the British Association for the advancement of Science; from the Association.

Collection of Drawings of the Ecole Impériale des Ponts et Chaussées, Paris; from the Ecole.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Transactions of the Institution of Engineers in Scotland; from the Institution.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Journal of the Architect and Engineer's Society for the kingdom of Hannover; from the Society.
Journal of the Royal United Service Institution; from the Institution.
Proceedings of the Royal Institution of Great Britain; from the Institution.
Transactions of the Royal Scottish Society of Arts; from the Society.
Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from the Association.
Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.
United States Patent Office Report; from the Commissioners.
Report of Parliamentary Committee on Patent Library and Museum; from Mr. Edward A. Cowper.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Bust of Mr. William Fairbairn; from Mr. Edward W. Wyon.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the last year :—

Description of a Machine for Breaking Limestone and Ore at Kirkless Hall Iron Works; by Mr. John Lancaster, of Wigan.

Description of a Horizontal V Pump; by Mr. John J. Birckel, of Liverpool.

On the improved Traversing Cranes at Crewe Locomotive Works; by Mr. John Ramsbottom, of Crewe.

Description of Harrison's Cast Iron Steam Boiler; by Mr. Zerah Colburn, of London.

On the Distribution of Weight on the Axles of Locomotives; by Mr. John Robinson, of Manchester.

On the Mechanical Appliances of the Loch Katrine Water Works for the supply of Glasgow; by Mr. James M. Gale, of Glasgow.

On the Construction and Results of Working of the large Steam Dredgers on the Clyde; by Mr. Andrew Duncan, of Glasgow.

On the Working and Capacity of Blast Furnaces; by Mr. Charles Cochrane, of Dudley.

On improvements in Heavy Tools for general Engineering and Iron Shipbuilding Work; by Mr. James Fletcher, of Manchester.

On the principal Seams of Coal and Ironstone in the Glasgow Coalfield; by Mr. William Moore, of Glasgow.

On the Construction of Blast Furnaces and the Manufacture of Pig Iron in the Cleveland district; by Mr. James George Beckton, of Whitby.

Description of a Coal Cutting Machine; by Mr. Thomas Levick, of Blaina.

On Puddling Iron by Machinery; by Mr. Henry Bennett, of Wombridge.

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Glasgow last summer, and in expressing their special thanks to the Local Committee, the Chairman Mr. Walter M. Neilson, and the Honorary Local Secretary Mr. J. Wyllie Guild, for their excellent arrangements and the very handsome reception that was given to the Members of the Institution on that occasion; and also their thanks to the authorities of the Edinburgh and Glasgow Railway for the special arrangements granted for the excursions; and to the proprietors of the works that were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works. The Council refer particularly to the great advantage afforded to the Members in the admirable opportunity provided them for visiting the important

works of the River Clyde Navigation and the Loch Katrine Water Works; and they offer their special acknowledgments to the President, Mr. Robert Napier, for the great pleasure afforded to the Members by his exceedingly kind and hospitable reception of them on that occasion, at his residence at Shandon. The Council look forward with confidence to the important advantages arising from the continuance of these Annual Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country and the opportunities of visiting the important engineering works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—cast iron boilers—incrustation of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—

injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES—particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—details of pit work of pumping engines at mines.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural

purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best

forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFER DAMS AND PILING, facts relating to construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire rope rigging—comparative strength and advantage of iron and wood ships.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES—shape and size—consumption of fuel—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The Papers are to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1864.

Cr.	£	s.	d.
By Balance 31st December, 1863	2365	15	10
„ Subscriptions from 11 Members in arrear	33	0	0
„ ditto from 495 Members for 1864	1485	0	0
„ ditto from 1 Graduate for 1864	2	0	0
„ ditto from 8 Members in advance for 1865	24	0	0
„ ditto from 3 Life Members	90	0	0
„ Entrance Fees from 62 New Members	124	0	0
„ Sale of Extra Reports	17	10	0
„ Interest from Bank	150	2	0
	£4291	7	10

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	526	10	6			
Less Authors' copies of papers, repaid	16	10	6	510	0	0
„ Stationery and Printing				58	12	8
„ Office Expenses and Petty Disbursements				62	19	0
„ Coals, Gas, and Water				20	2	7
„ Expenses of Meetings				62	8	6
„ Fittings and Repairs				8	1	6
„ Travelling Expenses				32	19	6
„ Parcels				4	9	2
„ Postages				57	11	0
„ Insurance				3	10	9
„ Salaries				450	0	0
„ Rent and Taxes				118	13	9
Balance 31st December, 1864				2901	19	5
				£4291	7	10

(Signed) EDWARD JONES, WALTER MAY, } Finance Committee.

26th January, 1865.

MEMOIRS

OF MEMBERS DECEASED IN 1864.

JAMES ALLEN was born at Poynton near Stockport in 1824, and after serving his apprenticeship with Messrs. Cole, engineers, Bolton, was engaged as an engineer in the construction of the Leeds and Thirsk Railway. Having given his attention for a considerable time to improvements in the construction of the brass fittings of engines and boilers, he subsequently became partner in the brass and copper works of Messrs. Allen Harrison and Co. in Manchester, in which he continued for the last ten years of his life. He was elected a Member of the Institution in 1856, and died on 11th December 1864, in the fortieth year of his age.

WILLIAM HARRISON BARWELL was born at Leicester on 3rd November 1822, and at an early age entered the Eagle Foundry, Northampton, belonging to his father, in which he became a partner in 1853, and thenceforth had almost the entire management of the works until his death, which occurred from a sudden illness on 9th November 1864, at the age of forty-two.

WILLIAM STEEL BROWN was born at Innerkip near Greenock in 1835. After serving his time under Mr. Kirtley in the locomotive works of the Midland Railway, Derby, he had the charge of an engine station on that line, and subsequently on the Great Northern Railway at the locomotive works, Peterborough, until his appointment in 1861 as locomotive superintendent of the Edinburgh and Glasgow Railway. His death took place after a short illness on 25th May 1864. He was elected a Member of the Institution in 1863.

JOHN FOWLER was born at Melksham, Wiltshire, on 11th July 1826. He was at first engaged in the corn trade, but in 1847 entered the engineering works of Messrs. Gilkes Wilson and Co. of Middlesbrough. Whilst in Ireland in 1849 he was impressed with the great necessity that existed for drainage in reclaiming the waste lands of that country, and conceived the idea that some mechanical system for executing drainage work could be introduced, by which the great expense of manual labour might be avoided; and in the following year he joined Mr. Albert Fry in some works at Bristol for this purpose, and commenced experiments which resulted in the successful completion of the draining plough. Although horse power was at first used for these draining ploughs, a very short time elapsed before steam was successfully applied to them; and Mr. Fowler, finding that he was then able to lay clay drainage pipes at any required depth, entered into large draining contracts in the south of England, to which he devoted himself for about five years. During this time he was also studying the application of steam power to the cultivation of the soil, and from 1852 his attention was constantly directed to this subject; the success which attended the application of steam power to draining machinery leading him to the idea of applying the same power to the cultivation of land. A series of experiments which he conducted at Ipswich in 1856 convinced him that this idea was practicable; and he ultimately exhibited a set of steam ploughing machinery at the Chester meeting of the Royal Agricultural Society in 1858, which gained the £500 prize. In 1857 he read a paper to the Institution on steam cultivation, in which he gave an account of the progress of the draining plough to maturity, and of the progress then made and the results attained in the application of steam power to the cultivating plough. Although the desideratum of steam cultivation was now practically effected, most serious obstacles presented themselves against bringing the invention to perfection, not only from unforeseen mechanical difficulties owing to the physical peculiarities of the land in different localities, but also from the very general ignorance of the agricultural classes in reference to engineering. Mr. Fowler's indomitable energy however enabled him to surmount

all the obstacles met with, and the practical application of steam power to agriculture became gradually so much extended, both in England and on the Continent, that in 1861, in conjunction with the late Mr. Hewitson and Mr. Kitson, he established works in Leeds specially devoted to the manufacture of his machines. These works were subsequently extended and carried on by Mr. Fowler up to the time of his death, with his brother Mr. Robert Fowler. He was elected a Member of the Institution in 1857, and died on 4th December 1864 from the results of an accident, at the age of thirty-eight.

JOHN HEDLEY was born in 1817 near Fatfield in the county of Durham, and served his apprenticeship with Mr. Robert Clark at the Lambton Collieries, and was afterwards manager at the Bishopwearmouth Iron Works, Sunderland. In 1841 he was for a short time engineer at Whitworth Colliery, and thence went to South Hetton and Murton Collieries, where he remained with the exception of a short interval till 1863 when he resigned from ill health. At the Murton Colliery he erected all the machinery with which the well known Murton winning was sunk through the immense feeders of water contained in the sand underlying the magnesian limestone. He was also extensively engaged in general practice as a mechanical engineer and in the valuation of colliery plant; and was the inventor of "ring cribs" for strengthening the cast iron lining of pit shafts, and of an improved system of guides for cages, in which malleable iron rails are substituted for the ordinary wooden slides. He was elected a Member of the Institution in 1858, and died at Newcastle-on-Tyne on 11th September 1864, at the age of forty-seven.

EDWIN MARSHALL was born on 28th October 1814 at Birmingham, and in 1834 commenced business with his father, a timber merchant in Birmingham. In 1848 they began building railway wagons; and in 1850, in conjunction with Mr. Brown, a coach builder, became railway and general carriage builders, and commenced one of the earliest establishments for the construction of railway carriages, as

the firm of Messrs. Brown Marshalls and Co. In 1855 they erected for the purpose the Britannia Carriage Works, at Upper Saltley, Birmingham, where were manufactured the carriage and wagon stock for many foreign railways. Mr. Edwin Marshall died after a long and severe illness on 8th May 1864, aged forty-nine years. He was a Member of the Institution from 1848.

George Mackay Miller was born in London on 7th December 1813, and in 1829 was apprenticed to Messrs. Lloyd, millwrights and engineers, Southwark. In 1835 he was engaged in the office of Mr. John Dixon, then resident engineer under Mr. George Stephenson on the Manchester end of the Liverpool and Manchester Railway; and in 1837 was transferred to Mr. Robert Stephenson's office in London, upon the London and Birmingham Railway. In 1838 he was appointed resident engineer and manager of the London and Greenwich Railway, which he worked for six years. In 1844 he was sent out by Mr. Locke to Jamaica, for the purpose of making and organising the short line of railway from Kingston; and in 1847, when the line was finished, he returned to England. In the same year he was appointed resident engineer and locomotive superintendent of the Great Southern and Western Railway of Ireland, of which 56 miles length was then opened for traffic. In 1849, when the line was opened to Cork, he took the whole charge of the line and works, and became the chief engineer for all departments of the railway; and had ultimately the entire control of nearly 400 miles of railway, including the works and rolling stock. This position he held for nearly seventeen years till the time of his death, which occurred after a short illness on 4th January 1864, at the age of fifty. He was elected a Member of the Institution in 1853.

William Simpson was born in London on 29th July 1809, his father, Mr. Thomas Simpson, being the promoter and founder of the Chelsea and Lambeth Water Works. He devoted himself to the mechanical branch of engineering, and was the active partner in the firm of Messrs. William Simpson and Co., of Pimlico, from

its commencement until the end of 1862, the works being established for the manufacture of steam engines and machinery, especially in connection with hydraulic works. By this firm were constructed the pumping engines on the double cylinder principle, working with high and low pressure steam in combination, now so successfully used by the Chelsea, Lambeth, and New River Water Works; and a paper on the construction and results of working of these engines was communicated through him to the Institution in 1862. He died on 7th May 1864, at the age of fifty-four, by falling from a steamer whilst returning from the Isle of Dogs, where he had recently established some iron shipbuilding and general engineering works. He was elected a Member of the Institution in 1862.

Charles Lingard Stokes was born in Gloucestershire in 1826, and served his time in the locomotive department of the London and South Western Railway with Mr. John V. Gooch. In 1850 he joined the Eastern Counties Railway, and remained there until 1855, when he was appointed locomotive superintendent of the East Indian Railway; in which capacity he was one of the early pioneers of the locomotive system in India, and afforded the government important assistance during the Indian mutiny by his unwearied devotion in working the railway from Calcutta during that eventful period. At the instigation of the Governor General, the late Lord Canning, he constructed two steam vessels on the Ganges for the conveyance of troops on that occasion: the first vessel was built with extraordinary rapidity, and was worked by two locomotives with their engines and boilers complete, adapted with great ingenuity to the purpose. The mental anxiety and exposure suffered during the mutiny, combined with the insidious effects of the climate, caused his health to give way; and he was ultimately compelled to resign his appointment, and returned home in 1862. He died rather suddenly on 19th January 1864, at the age of thirty-seven. He was elected a Member of the Institution in 1857.

WILLIAM HENRY WOODHOUSE was born at Overseal, Leicestershire, in 1815, and was originally intended for a country life, but his inclination afterwards led him to take up civil engineering as a pursuit. In 1844 he became connected with Mr. Liddell in the construction of the Leicester and Burton branch of the Midland Railway. He afterwards became associated with the Submarine Telegraph Company; and having gained some experience in the laying of submarine telegraph cables in the Irish Channel, went out during the war with Russia in 1854 in charge of the cable which was successfully laid and established as a submarine telegraph between Balaklava and Varna. He subsequently joined the Atlantic Telegraph Company, and went out in 1858 in the "Niagara" for laying the western portion of the cable. Upon his return to England, and pending the completion of the new Atlantic telegraph cable now in course of construction, he was engaged in various civil engineering works. He became a Member of the Institution in 1861, and died in London on 25th June 1864, at the age of forty-nine.

The PRESIDENT congratulated the Members upon the advancing prosperity of the Institution and the rapid progress it had made in the number of Members and increase of funds, and in the value and interest of the papers communicated; he had no doubt it would still continue to advance in prosperity and importance by the united exertions of the Members. He moved that the Report of the Council be received and adopted, which was passed.

The PRESIDENT announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were found to be duly elected for the ensuing year:—

PRESIDENT.

ROBERT NAPIER, ...	Glasgow.

VICE-PRESIDENTS.

CHARLES F. BEYER, . . .	Manchester.
WILLIAM CLAY, ...	Liverpool.
ROBERT HAWTHORN, . . .	Newcastle-on-Tyne.
SAMPSON LLOYD, ...	Wednesbury.
HENRY MAUDSLAY, . . .	London.
JOHN RAMSBOTTOM, . . .	Crewe.

COUNCIL.

EDWARD A. COWPER, . . .	London.
GEORGE HARRISON, . . .	Birkenhead.
EDWARD JONES, ...	Wednesbury.
WALTER M. NEILSON, . . .	Glasgow.
CHARLES P. STEWART, . .	Manchester.
JOHN VERNON, ...	Liverpool.

PAST-PRESIDENTS.

Ex officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, .	Newcastle-on-Tyne.
JAMES KENNEDY, ...	Liverpool.
JOHN PENN, ...	London.
JOSEPH WHITWORTH, . . .	Manchester.

COUNCIL.

Members of Council remaining in office.

Alexander Allan,	Perth.
John Anderson,	Woolwich.
Frederick J. Bramwell,	London.
Charles Cochrane,	Dudley.
John Fernie,	Leeds.
Sir Charles Fox,	London.
Edward Humphrys,	London.
Walter May,	Birmingham.
C. William Siemens,	London.

TREASURER.

Henry Edmunds,	Birmingham.

SECRETARY.

William P. Marshall,	Birmingham.

The following New Members were also elected:—

MEMBERS.

John Gay Newton Alleyne,	Alfreton.
Martin Baldwin,	Bilston.
William Bass,	Workington.
Henry Bennett,	Wellington, Salop.
George Henry Benson,	Deepcar.
Martin Benson,	London.
David Kirkaldy,	London.
Sverier Hakon Lundh,	London.
James Robert Mosse,	Mauritius.
Samuel Rideal,	Manchester.
Bernhard Samuelson,	Banbury.
Arthur Sparrow,	Stoke-upon-Trent.
George Arthur Waller,	Dublin.
Thomas Walpole,	Dublin.

HONORARY MEMBERS.

Otto Gössell,	London.
John Hall,	Manchester.

The following paper was then read:—

ON THE RELATIVE ADVANTAGES OF THE INCH AND THE METRE AS THE STANDARD UNIT OF DECIMAL MEASURE.

By Mr. JOHN FERNIE, of Leeds.

The subject of a Decimal System of Measure resolves itself into two distinct questions, the *desirability* of a decimal system, and the *standard of measure* to be adopted as the unit of the decimal system.

The principle of a decimal system of measurement is now considered to be so advantageous and desirable by the practical and scientific men who have entered into the subject, that sooner or later the irregular and inconvenient system hitherto used in this country must be expected to give place to one more suited to the present times. The permissive bill of 1864, which legalised by Act of Parliament the use in this country of the present standards of measure decimalised, and also of the French standard the metre, is the first public step in that direction; and consequently the question as to which standard is to be finally and exclusively adopted for use in this country has now become an important and urgent practical question. The adoption of the Metre system in its entirety, both for measures and weights, has been strongly advocated by a very influential committee, who are actively endeavouring to effect that purpose; and the object of the present paper is to compare the standards for measure of length, and to show the practicability of adopting a decimal system founded on the Inch at present used in this country, and the advantages that the inch possesses over the metre as the standard unit of measure.

The first question of the *desirability* of a decimal system of measure may now be considered settled, and the principle definitely adopted in this country: but the second question of the *standard of measure* is still open, and is a very important one for consideration on account of the number of circumstances affecting it.

The adoption of the Metre has been strongly recommended, and special efforts were made to get it fixed upon as the compulsory standard of measure for this country; but in the decimal bill now passed it is determined only to legalise the use of the metre in addition to the former standards in this country. The grounds on which the adoption of the metre has been urged are, the existence already of a complete decimal system of measure and of weights based on the metre, and its adoption already as the standard of measure by the large and important population of the French empire and several other countries: the object being to obtain if possible a universal standard of measure for the whole civilised world, on account of the great advantages that would attend the universal use of the same system of measures in the rapidly extending international communications.

The consideration of the *standard of measure* involves two distinct classes of requirements that have to be met as far as practicable, which need a separate examination, namely:—those involving *scientific questions* for preliminary investigation; and those that are *practical conditions* necessary to be fulfilled before the object can be really carried out.

The scientific questions involved may be stated as follows:—

1st. The standard to be the one that can be replaced best in case of being accidentally lost.

2nd. The standard to be the one most universal in the character of its basis of reference.

The practical conditions involved may be stated as follows:—

3rd. The standard to be the one best suited for use in decimal subdivision.

4th. The standard to be the one most extensively and influentially in use already, and consequently involving the least alteration of existing measures.

1st. In considering the question of the standard that can be *replaced best* in case of being totally lost by any accident, there appears on examination to be no real choice between the metre and the inch in this respect. The length of the Metre was originally

determined by measuring a portion of a quadrant of the earth's polar circumference; but its length was also referred to the length of a seconds pendulum, on account of the much greater facility for accurately repeating the measurement of a pendulum than the extremely difficult and complicated operation of measuring an arc of the earth's circumference. The length of the metre was consequently defined in 1798 by Borda, one of the commissioners for determining the French national standard, by giving 0·99385 metre as the length of a seconds pendulum at Paris making 86,400 oscillations in twenty-four hours and vibrating in vacuo at the sea level and at the temperature of freezing water.

The length of the Inch was defined in 1824 by the declaration by Act of Parliament that 39·13929 inches is the length of a seconds pendulum in the latitude of London vibrating in vacuo at the sea level and at the temperature of 62° Fahrenheit. Consequently both the metre and the inch can be verified by the same means, the measurement of a pendulum; and indeed the relation between them having been once established, it follows that whatever means is used for verifying the one, whether by the length of the pendulum or any measurement of the earth's surface, is equally available for verifying the other; so that in this respect there is not any choice between the metre and the inch.

2nd. In regard to the second point—the standard that is *most universal in the character of its basis* of reference—the metre was formerly supposed to have a marked superiority over the inch, as it was originally intended to be exactly the 1-10 millionth part of a quadrant of the earth's polar circumference,* the basis of measurement to which it was referred; whilst on the other hand the inch was an uneven fraction of the length of the pendulum. The result however of subsequent and more accurate measurement

* NOTE.—Or more correctly the 1-100,000th part of a decimal degree of latitude of which 100 degrees made the quadrant, this degree being taken in France and consequently differing in length from a similar degree in other latitudes on account of the polar diameter of the earth being 1-299th part less than its mean equatorial diameter, owing to its spheroidal form.

has been to show an error of 1-6404th part deficiency in the original measurement of the metre, which was effected in 1794 by the measurement of an arc of about 630 miles length, extending through France from the coast at Dunkirk to Formentera on the coast of Spain, the measurement of which was carried out under unusual difficulties in time of war. In consequence of this error in the original measurement for the standard, the length of the metre has now to be defined by an uneven fraction, as is the case in defining the length of the inch. The further result however of recent investigation has been to show that a quadrant of the earth's polar circumference is not, as was previously supposed, a uniform quantity, and it is therefore not a suitable basis for determining a standard unit of measure; for it has been found that the form of the earth at the equator differs from a true circle, its longest equatorial diameter exceeding its shortest by 1-3941th part, and there is consequently a variation in the lengths of different quadrants of the circumference measured from the pole to the equator. As regards the universality of its basis therefore, there is no choice between the metre and the inch.

It has to be noticed that the present legal standard of measure in this country is really an individual standard metallic yard measure, which was legalised by Act of Parliament in 1855; this had been prepared with all possible care by comparison of all existing standards of authority, the former legal standard, a metallic yard measure made by Bird in 1760, having been destroyed by fire in the burning of the Houses of Parliament in 1834. In consequence however of some sources of error having been discovered by subsequent investigations in the former process of measuring the seconds pendulum, all reference is omitted in this last Act of 1855 to the means of verifying the standard by the length of the pendulum, and the only provision made against a loss of the standard is by legalising certain duplicates that were made from it with the greatest care as secondary standards. The present standard of measure is therefore really an individual metallic yard measure, forming the legal standard independent of any reference to another source: and the metre may indeed be considered to be in a similar position, since it is a continuation or

copy of the original metre, which is now known to differ from the measure of the earth's circumference that it was intended to represent, while the amount of error at present ascertained may probably undergo still further correction by future still more accurate observations.

The circumstance however of depending upon accuracy of copying for the preservation of a standard, though theoretically objectionable, is not practically a disadvantage as regards accuracy. For with the extreme degree of perfection now attained in copying measures of length by Mr. Whitworth's process of contact measurement, the accuracy of measurement can be carried as far as one millionth of an inch, which is a considerably higher approximation than can be attained in any present process of determining the length of a pendulum or an arc of the earth's circumference. The writer is informed by Mr. Whitworth that the standard cylindrical gauges supplied by him to engineering and other establishments do not vary 1-10,000th inch in diameter for any size up to 2 inches, and the larger sizes up to 6 inches diameter do not vary 1-5000th inch.

In consequence of the variation in the lengths of the several quadrants of the earth's circumference, a suggestion has been made by Sir John Herschel to adopt the earth's polar axis as the standard of reference, that being the only single or unique dimension of the earth's mass. As this dimension is very nearly 500,500,000 inches or 1-1000th part more than 500 million inches, it has been proposed by him to increase the inch by 1-1000th part and make it then the standard unit of length as the 1-500 millionth part of the earth's polar axis. It has to be observed however in reference to this proposal, that 1-1000th part of an inch is now an appreciable quantity in mechanical work, such as boring rifles, &c.; and the alteration if carried out would involve a loss of one mile in every 1000 miles. Moreover, independently of these practical objections, any such step would really involve a similar mistake to that made in originally fixing the metre, since the results of future more correct measurements of the earth's axis would be likely to require a correction in the fraction expressing the inch, in addition to the

present known error of 1-170,000th part, arising from the actual length of the axis being rather less than 500,500,000 inches, as ascertained by the present measurement.

All these various considerations therefore appear to lead to the conclusion that the best practical course is to refer to an individual standard which will admit of being copied with a very high degree of accuracy, as in the case of the present legal standard in this country.

3rd. The next question, as to the standard *best suited for use in decimal subdivision*, is one to be determined by the relative practical convenience or inconvenience of the principal subdivisions and multiples of the different standards of length.

The old legal standard of measure in this country, the yard, is near the size of the metre, the former being 36 inches and the latter 39·3708 inches. If the yard were subdivided decimally into tenths, hundredths, and thousandths, it would make a scale as inconvenient and difficult of application in this country as the metre scale: but the standard is defined as a yard of 36 inches, and the inch as a unit of measure has important advantages as regards facility of application, and has a special qualification for the purpose as a convenient unit for expressing the smaller dimensions required in mechanical engineering work, since the subdivisions and multiples of the inch predominate in the dimensions of the parts of machinery, &c. For example, a measuring machine extending from 0 to 10 inches gives an ample range to make the requisite templates and gauges with an accuracy up to 1-1000th inch for all the boring and turning work required for locomotives and for stationary engines up to 100 horse power, and for the tools and machines of corresponding size. The larger dimensions above 10 inches are but few in number as compared with those below 10 inches, and are not required to be more accurate than to 1-100th inch; their dimensions can therefore be obtained from a steel rule of 100 inches length divided into inches, tenths, and half-tenths, while the half-tenth of an inch being easily divisible by the eye into five parts gives hundredths of an inch. The writer has found such a range up

to 100 inches amply sufficient for the requirements of one of the largest locomotive establishments, and also for all the purposes of a large ironworks; and with such a system great accuracy of work is obtained, mistakes and misfits are avoided, and a duplicate system of the most perfect kind is established.

For small dimensions the metre is divided into 1000 parts called millimetres, each being equal to ·03937 inch or about 1-26th inch: but in the classes of work in which the finer dimensions of thousandths of an inch are required, the inch has an advantage over the metre in convenience of application as the unit of measure; for dimensions in thousandths of an inch are readily and conveniently expressed and spoken of, but with the metre as a unit such dimensions require the use of millimetres and fractions of millimetres carried to two places of decimals in order to express them. For example, the standard bore of the government rifles, in which a difference of 1-1000th inch in the diameter of bore has to be recognised and expressed, is

·577 inch or 577 thousandths;

but the expression of such a dimension on the metre system would be in the inconvenient form of

14·67 millimetres.

This is a practical advantage of importance in favour of the inch as the unit of measure; for dimensions to 1-1000th inch are now required in regular use for various descriptions of work. For example, in the case of fixing a wheel or a lever upon its axle, the amount of difference in diameter required between boring and turning, in order to ensure the correct amount of tension, is not a thing to be guessed at, but is a definite quantity ranging from 1-1000th to 5-1000ths inch or ·001 to ·005 inch. If in addition to forcing on by hydraulic pressure, as in the case of putting wheels upon their axles, the further step is taken of expanding the external portion by heat and then shrinking it upon its seating, as in fixing levers upon shafts, a very high degree of accuracy in the respective diameters is required, in order to ensure a definite amount of tension: this is especially the case in the manufacture of wrought iron ordnance, where one series of hoops has to be shrunk upon

another, each layer being compressed in proportion to the work it is intended to sustain. These dimensions of 1000ths inch are now readily appreciated and worked to in regular work by means of the system of contact gauges introduced by Mr. Whitworth; they can be measured by any good workman with a pair of callipers, and great advantage in accuracy and facility of work is derived from the system of working to these definite decimal dimensions.

It may also be observed that the inch divided into 1000ths serves very conveniently to express the series of thicknesses known as the wire and metal gauges, as shown in Mr. Whitworth's decimal wire gauge, a specimen of which is on the table, extending from No. 300 or 300 thousandths of an inch to No. 18 or 18 thousandths of an inch.

A decimal scale founded on the inch as the unit would have then for its subdivisions the 100ths and 1000ths inch at present in use; and the first ascending step in the scale would be the substitution of a 10-inch foot for the present 12-inch foot, being a reduction of 1-6th in the present measure. The succeeding measures would be as shown in the following table, taking merely for the sake of comparison a similar nomenclature to that of the metre scale :—

	Inches.	
Milli inch =	·001	or thousandth of an inch.
Centi inch =	·01	„ hundredth „
Deci inch =	·1	„ tenth „
Inch =	1	the Standard Unit.
Deca inch =	10	$\frac{5}{6}$ foot of 12 inches.
Hecto inch =	100	about 1$\frac{1}{4}$ fathom „ 72 „
Kilo inch =	1,000	„ 1$\frac{1}{4}$ chain „ 792 „
Myria inch =	10,000	„ 1$\frac{1}{4}$ furlong „ 7920 „
	100,000	„ 1$\frac{1}{4}$ mile „ 63360 „

A corresponding decimal scale applied to superficial measure would be as follows :—

	Sq. ins.	
Square Inch =	1	
Square Deca inch =	100	about $\frac{1}{9}$ foot of 144 square inches.
Square Hecto inch =	10,000	„ $\frac{1}{4}$ pole „ 39,204 „ „
Square Kilo inch =	1,000,000	„ $\frac{1}{6}$ acre „ 6,272,640 „ „

In carrying out this change of the measures at present in use, it has to be observed that in consequence of taking for the unit the lowest of the present denominations—the inch—the important advantage is obtained that any dimension on the present system can be exactly expressed in the decimal system without any fractional remainder, and the only calculation required for the change is to bring the dimension into inches, which immediately gives its corresponding value in the decimal system. But if any other of the present measures, such as the foot or the yard, were taken as the unit, a troublesome calculation would be required for this purpose, just as in the case of adopting the metre for the unit; and the result would be an inconvenient fractional quantity, with its accuracy depending in many cases on the length to which the decimal was carried.

4th. The last consideration is the standard that is the *most extensively and influentially in use* already, and consequently involves the least alteration of existing measures in its adoption.

The *metre* was established in France in 1840, and is now the measure in universal use throughout the French empire, and also in Belgium, Holland, and Northern Italy. It has also been subsequently adopted and has partly come into use in Spain, Portugal, Italy, and Greece, and also in Brazil, Peru, Chili, Mexico, and other countries in America. The population of the above countries is about as follows, taking the data from the *Almanach de Gotha*:—

			Population.
Metre in universal use	France, Belgium, Holland, and Northern Italy,	.....	50,000,000
Metre adopted and partly in use	European Countries	37,000,000	
	Ditto Colonies	35,000,000	
	American Countries	26,000,000	
			98,000,000
			148,000,000

The *inch* is in universal use throughout the British empire (excepting India) and throughout the North American States. In British India the native standard measure, the "hath," is legalised as 18 inches; and a multiple of the inch is also the standard

measure of the Russian empire, the imperial "sagene" being legalised as 7 feet English. The population of the above countries is about as follows, taken from the same source :—

			Population.
Inch in universal use	British empire (excepting India)	36,000,000	
	North American States	31,000,000	
			67,000,000
Multiple of Inch in use	British India	138,000,000	
	Russian empire	74,000,000	
			212,000,000
			279,000,000

In addition to this excess in the actual numbers of the people now using the inch over those now using the metre, the fact should be considered that the former include the great machinery producers, whose work is already existing in such large quantities in all parts of the world in the form of engines, machinery, railway plant, tools, &c.; such as the tools and machines of Manchester and Leeds, so largely exported to other countries, their cotton and flax machinery, the sugar mills of the West Indies, the steam engines, agricultural engines, and machinery sent to all parts of the world, steamboats, railway plant and machinery, railway bridges and roofs, &c.; the amount of steam engines and machinery alone that has been exported from this country during the last twenty years having reached the value of £49,000,000, and averaging during the last five years about £4,000,000 annually. The large excess in the machinery already made under the inch over that made under the metre system of measure is an important practical consideration, as it must be remembered that the machines sent out to other countries form types of other machines, and that they require repairing and renewing with the same measures with which they were made. In this country the inch is involved intimately in all mechanical engineering work, and is the basis on which the various machines and engines have been built, as the mechanical engineer may be said to think in inches, calculate in inches, and work in inches; mechanical drawings are made to the inch or its multiples, patterns are in inches, the pitches of the teeth of wheels, the sizes of taps and dies, the standard gauges for boring and turning, and the finer

dimensions of every part of every tool, machine, and engine, are all made in inches; and the sizes of all bars of iron and planks of timber are in inches. The inch is also the basis of the data for calculations of strength of materials, sectional areas of girders and framing, pressure of steam, &c., power, velocity, capacity, and weight. The difficulty of effecting any change in the unit now forming the basis of these measures and calculations would therefore be exceedingly great; but in the case of the metre this difficulty is greatly increased by the relation between the metre and the inch requiring a long fraction to represent it with sufficient accuracy for such purposes, thus:—

1 metre is equal to 39·3708 inches and
1 inch is equal to 25·3995 millimetres.

In the following Table are shown, for the purpose of comparison, the corresponding values in millimetres of some of the ordinary fractions of the inch, and the corresponding values of square and cubic inches in square centimetres and cubic millimetres; from which will be seen the extreme difficulty and inconvenience that would arise in attempting to change the inch to the metre system.

1	inch	= 25·3995	millimetres.
½	„	= 12·6998	„
¼	„	= 6·3499	„
⅛	„	= 3·1749	„
1/16	„	= 1·5875	„
1/32	„	= 0·7937	„
1/64	„	= 0·3968	„
1/100	„	= 0·2540	„

1	square inch	= 6·451	square	centimetres.
10	„ „	= 64·512	„	„

1	cubic inch	= 16·386	cubic	millimetres.
10	„ „	= 163·862	„	„

Considering the preponderance of the population now using the inch and not the metre, and the extent to which the inch is now spread over the whole world, the difficulties in the way of a change to the metre appear to the writer so insuperable as to amount practically to a prohibition of a decimal system of measure if it is to be based on the metre.

The subject of decimalising the present very irregular and inconvenient system of *Weights and Measures of Capacity* in this country is one of great importance; and great advantages would arise from their reduction to a uniform decimal system. It has been supposed that the metre system has an advantage in basing the system of weights directly upon the measures of length, the kilogramme of 2·2048 lbs. English being intended to be exactly the weight of a cubic decimetre of pure water at its maximum density: but it now appears from subsequent more accurate measurement that this requires some correction, so that the relation between the kilogramme and the metre is not an even one as intended, but an uneven fractional one. There is strictly no choice therefore in that respect between the kilogramme and the pound; and in fact, in the same way as with the definition of the metre or the inch, any weight, such as the English pound, may be defined with equal accuracy for the standard unit.

It may be remarked that if the pound (pound avoirdupois =7000 grains troy) were taken as the standard unit for decimal weights, the important weights of the cwt. and the ton, which now vary in practice, the cwt. between 112 and 120 lbs. and the ton between 20 and 21 cwts. or 2240 and 2520 lbs., might be decimalised as 100 and 2000 lbs. without any very serious difficulty and with important advantage in removing another of the old irregularities in the system of weights and measures; just as in 1841 the imperial and decimal gallon consisting of 10 lbs. of distilled water at 62° Fahr. was substituted by Act of Parliament for the old ale and wine gallons having 102 and 83 per cent. respectively of the same value.

The following are the general conclusions submitted in the present paper in reference to the standard for decimal measure:—

I.—That the inch and the metre are equally eligible for the purpose, as regards the basis of reference on which they are founded; and either of them could be as accurately and readily replaced as the other in case of being lost: since both of them are practically dependent upon the copying of an individual standard,

which can be effected by the present improved means of measurement with a higher degree of accuracy than could be attained in a repetition of the original process of constructing the standard by reference to a natural standard such as a pendulum or an arc of the earth's circumference.

II.—That the metre is not suitable for adoption in this country, on account of its entire difference from the existing measures and the inconvenience that would arise in expressing the smaller dimensions extensively used in mechanical work, &c.; and that the inch is the most suitable measure for the purpose, on account of its being intimately involved in the present data for calculations and dimensions of mechanical work, &c., and from its convenience for expressing the smaller dimensions extensively used. That for larger dimensions the easiest and most convenient decimal change would be the adoption of a 10 inch measure, which would be a reduction of an even fraction of 1-6th from the present foot; and the longer measures being already multiples of the inch, the change would then be at least easier for their decimal adaptation to the inch than for their entire alteration to the metre standard.

III.—That it is very desirable that an alteration should be made in the present system of weights and measures of capacity, for reducing them both to decimal systems; and that these can be based as definitely and conveniently upon the inch as the standard of measure as upon the metre; and that it will be preferable to adopt for the standard a weight that is already in most common use in this country, such as the pound, without attempting to construct any new standard bearing a more simple relation to the decimal standard of length, but differing from all the existing weights.

Mr. FERNIE said he had endeavoured to enter upon the subject of the paper without any bias for either the inch or the metre; and after a good deal of consideration of the question he had come to the conclusions given in the paper, in favour of the inch as the standard unit of decimal measure. In the estimates of the population using the inch or the metre he had found some difficulty in obtaining reliable information respecting this for the different countries; and was partly indebted to a paper read by Professor Rankine at last year's meeting of the British Association at Bath, and partly also to a paper by Sir John Herschel on the yard, pendulum, and metre; it was probable therefore that a different view of the relative populations on either side of the question might be entertained by the advocates of the metre system. With regard also to the value of the exportations from England of machinery constructed on the inch system, which had been referred to in the paper, a small deduction had to be made for machinery constructed on the metre system, as a few of the locomotive establishments in this country had had to send out engines made on the metre system to France and Italy; but generally speaking the engines and machinery made in England had been all constructed upon the inch as the standard of measurement. The only instance that he knew of in which the metre had been entirely adopted in this country as the basis for working upon was the manufacture of Giffard's injector for steam boilers, made at the Atlas Works, Manchester. The injector was however altogether a French invention, and the drawings required for its manufacture were all sent over from France in the first instance with the dimensions marked in millimetres; and as the proportions of the parts were so very delicate, it was feared they might be disturbed by turning the measurements into inches, and the metre had therefore been adhered to as the basis of measurement in that particular branch of work. It would certainly be most difficult to induce the French to adopt the inch; but on the other hand he did not think it was practicable to introduce the metre system universally in English engineering workshops, as the expense of the change would be so great and he did not see that there would be any advantage in it at all. He therefore considered

the inch preferable as the standard unit of decimal measure in this country.

The PRESIDENT said that a deputation had been sent to the present meeting from the International Decimal Association, and he hoped they would give their views upon the subject of the paper that had been read.

Mr. JAMES YATES, as a Vice-President of the International Decimal Association, said he had been particularly gratified to find that the views expressed in the paper coincided so fully with those of the Decimal Association, with regard to the value and practicability of the decimal system of measurement; there was indeed little difference of opinion excepting in the ultimate conclusion drawn as to the standard unit for decimal measure, for which the metre was considered by the Association the most eligible. There was no question that the mode of measurement hitherto used in this country was so irregular and inconvenient that it ought to be abandoned, and a uniform decimal system substituted for it; and the introduction of such a uniform system universally throughout the world would be attended with most important advantages, from the rapidly extending international communications. The two practical conditions affecting the choice of a universal standard unit of measure were, that it should be the one best suited for use in decimal subdivision; and that it should be the one causing the least possible alteration in the existing measures. The question was thus brought into a very narrow compass: namely, whether the preference should be given to the inch or to the metre as the unit of measure; the latter being defined by the platinum metre preserved since 1799 in the *Hotel des Archives* in Paris, and the former by the gunmetal yard measure or bar deposited in 1855 in the office of the Exchequer at Westminster.

The course adopted by the International Decimal Association, in order to obtain a solution of this question as to the best unit of length, had been to send a series of eleven questions to all the persons who were supposed to be best qualified to judge upon the subject; and the answers having been received, four meetings were held in London, to which all such persons were invited; and on that

occasion Mr. Whitworth's system of accurate measurement was exhibited and explained. The result of the discussion of the question at the meetings was that a report was drawn up and circulated, in which it was recommended as eminently desirable that the unit of measurement should be of such a length as might be adapted to measure the greatest variety of objects, and in the most numerous cases likely to occur in daily life; and that it should be visible at a glance of the eye, and easily carried about and manipulated: and it appeared that for these purposes the inch or the foot would be too short, and the fathom too long; and that a measure of about the same length as the ell, the yard, the metre, or the second's pendulum was to be preferred, of which there were important reasons for selecting the metre as the universal unit. The inch indeed seemed at the outset very unsuitable to become the basis of a universal system; and although for English mechanical engineers it might be a very convenient measure, yet even for their purposes he was not satisfied that it would be better than the metre, by the use of which he thought all measurements in mechanical work might be made with equal nicety and accuracy. In the ordinary transactions of daily life the commonest and most universal measurements might be taken as those associated with textile manufactures; and the metre being a measure suitable for cases of this kind would be the most convenient for common use and most eligible as the standard unit of lineal measurement. For example, an order for 13 metres of silk or 64 square metres of carpet was simple in expression and would convey a clear conception of the quantity, if the metre system were adopted, and the unit would be very near the yard now used for the purpose; whereas with the inch as the unit, the equivalent expressions of 510 inches length or 99000 square inches respectively were very inconvenient and not very easily conceived. Such illustrations showed clearly the inconvenience of using a small unit; and led to the conclusion that, in fixing a standard unit of measurement, it was necessary not to have regard to any special purpose exclusively. In aiming solely at the small measurements that predominated in mechanical engineering work, the inch might be the best; but when a standard

was required for all sorts of measurement, the inch was in his own opinion unsuitable for general use.

For the purpose of minute subdivision every advantage was presented by the metre which was attainable by the inch; since the accuracy of minute measurements depended not on the scale, but on the instrument, which could of course be made equally applicable to any scale. The most recent instrument for minute measurements in connection with the metre system was that of M. Perreaux of Paris, which was shown in the Great Exhibition of 1862, and afforded the means of measuring to 1-3000th of a millimetre (about 13 millionths of an inch); and for all practical purposes that was probably as minute and exact a measurement as was required. It should be remarked that Mr. Whitworth himself, who had recommended the inch to be adhered to for mechanical engineering work, objected to the prototype yard from which the inch was supposed to be taken, because it could not be seen or used; and had shown that it was hardly to be called a measure at all, and was inapplicable and of no value whatever in mechanical operations. The Astronomer Royal too had admitted that the chief value of this standard yard was its convenience for geodetic operations. For these purposes however the metre was at least equally eligible; and the difficulty that was anticipated from converting the present measures of this country to the metre system, on account of the number of decimal places required, would be met by the use of ready reckoners, specially adapted to all the purposes of commerce; these would be requisite until the metre was fully established in general use, after which the need of any such aids would cease.

With regard to the relative population in favour of the inch and the metre respectively, he believed the numbers given in the *Almanach de Gotha*, as the population at the present time of all the countries in the world, were generally accepted as the best authority on the subject; and from these data he had come to the conclusion that the population in favour of the metre should be taken as about three times that using the inch, instead of the majority being in favour of the inch as argued in the paper. Russia with a population of 74 millions appeared to have been put down as favourable to the

inch, because it used the "sagene" of 7 feet English or 84 inches. This measure, which was the Russian fathom, had been fixed at a time when the length of that fathom was very uncertain, by Peter the Great, who decided that it should be exactly equal to 7 feet English. It had been stated however by Mr. Kupffer, the imperial superintendent of weights and measures in Russia, that although the inch was known in Russia as the 1-84th part of their standard unit, it was not used by any means in the same manner or to the same extent as the inch was used in England: on the other hand he instanced many points in which the present weights and measures in Russia approached very nearly to the metre system; and he expressed his opinion that it would be far easier for Russia to adopt the metre system than for England to do so, and he decidedly considered the metre system was preferable for Russia to the inch system. A report had also been presented to the Minister of Finance, by the Imperial Academy of Sciences in St. Petersburg, in which the adoption of the metre was recommended for Russia; and there was therefore some ground for saying that Russia was decidedly tending to the adoption of the metre. The different states forming the Germanic Confederation had formerly been exceedingly confused in their weights and measures, and had recently appointed commissioners to devise a uniform system, who recommended the adoption of the metre system throughout all Germany. A meeting of the several representatives was then held at Frankfort-on-the-Maine, when all the states except Prussia agreed to adopt the recommendation of the commissioners; and at length in 1863, when the statistical congress was held in Berlin, Prussia also gave in its adherence to the metre system: thus all Germany might now be fairly reckoned on the side of the metre. Moreover Germany had for a long time past made a partial use of the metre system, the half kilogramme having been employed as the standard unit of weight in the custom house, the post office, the railways, and other public departments. In India also there was a movement going on which was favourable to the metre system, and recent extracts from the *Madras Times* showed that that district of India was considering the subject and

inclining to the metre. On the whole therefore he thought that Germany and Russia should be added on the side of the countries favourable to the metre, and India should at least be omitted from the number for the inch; and the population favourable to the metre would then be more than 200 millions, in comparison with about 70 millions actually using the inch at the present time.

An important movement was now going on in this country for introducing the metre system in education, since it was clear that the system could not be brought into universal use unless it was first taught universally in schools. He had found a widely prevalent desire on the part of schoolmasters and others interested in education to have the metre system taught in schools to all classes of the community, and it was astonishing to see the amount of facility with which the system was learnt. He exhibited a diagram of the measures and weights of the metre system (Dowling's synoptic table), by means of which he was confident any child might be made to understand the principles of the system thoroughly in a few hours; and if the system were taught for three months in any of the elementary schools, the children would become quite familiar with it. But on the other hand it was well known that the present confused tables of weights and measures were a continual torment to the learners, who had no sooner got them by heart than they began to forget them. The metre system however was not intended to be rendered compulsory in this country at present, but to be publicly taught and by that means gradually introduced, and not made compulsory until the nation was fully prepared for it.

He was happy to acknowledge the favourable opportunity that had been afforded by the paper just read for a practical discussion of the subject in one of its many important bearings; and such a course could not fail to contribute to the satisfactory settlement of this important international question.

Mr. F. P. Fellows, as a member of the deputation from the International Decimal Association, observed that in considering any change of weights and measures the subject should be regarded in all its bearings, in relation to all classes of the population, and not in reference to mechanical engineering only; because what

mechanical engineers wanted for their own work might not be so good perhaps for other purposes. Whatever the unit of measure might be, there was no difference of opinion at all as to the great benefit of a uniform decimal system for all weights and measures. It was true that in the earlier stages of civilisation, when calculations were not put down in writing, the binary system would be most readily employed; but with a written scale of figures the decimal system founded upon the basis of the scale was undoubtedly superior to all others. The great disadvantage in his opinion of decimalising the inch, as the unit of measure in England, was that every other measure of length or capacity would then have to be changed, since the inch had no decimal relation to the other measures of length, area, capacity, and weight. Under such a system therefore the inch would be the only one retained of all the English measures, and the rest must all be altered, involving nearly if not quite as much difficulty as an entire alteration to the metre system. The same remark of course applied in taking any other English measure as the unit; and although in relation to decimal measurement the question of the standard unit of measure was in the abstract of secondary importance, yet the practical objection to setting up any other unit instead of the metre was that there would then be two standard units, and the advantages of a universal system would be lost. Hence, if it were on this ground alone, he thought the adoption of the metre system was highly desirable in this country; and it had the advantage of being a system ready made to hand, perfectly carried out, and already tested in actual use. The whole metre system of weights and measures was connected decimally with the metre: the cube of a centimetre filled with water weighed 1 gramme, which was the unit of weight; the cube of a decimetre gave the litre, or unit of capacity; the cubic metre or stere was the unit of cubic or solid measure; and the square of a decametre gave the are, or unit of square or superficial measure. In this way every unit of weight and measure was obtained at once direct from the metre, which was thus the basis of the entire system. The same advantages could not be attained by any other method except under a similar decimal scale;

and hence the desirability of taking at once the same unit as the basis of the system, and thus adopting the metre system in its integrity, with the whole of its weights and measures, and similar designations for the several quantities.

In connection with the question of population, as bearing upon the adoption of the metre as the unit of decimal measure, was the amount of the home produce exports from this country to the countries favouring the metre system and to those using the present English weights and measures. It appeared that in 1861 the value of the home produce exports to countries using the metre system amounted to as much as 55 million £, while the exports to countries using the English system came to only 24 million £; and further, that in the eight years from 1853 to 1861 the exports to the former countries had increased in value from 32 to 55 million £, while those to the latter countries had actually decreased in the same time from 43 to only 24 million £. He therefore thought that any alteration in the weights and measures of this country should be made so as to suit the great bulk of our customers and those who had increased and were increasing their trade with this country to the greatest extent. The question had been brought before the associated Chambers of Commerce, and urged upon this ground; and they came to the unanimous conclusion that in any change it was desirable to adopt the metre system, because it would simplify all foreign transactions. It would also extend to commerce the advantages already experienced in the sciences from the use of a universal nomenclature in each science, whereby scientific men in different countries were enabled to interchange their ideas upon any subject without being minutely conversant with the languages of other countries than their own; and such an advantage in the case of weights and measures was a most important point to be kept in view in making any change.

It had been advanced as a reason for still retaining the inch and using it as the basis of the decimal system in this country that it had existed already from some thousand years. But on the other hand it appeared that the metre system, which had only been established about thirty years, and had been adopted in the first

instance only by a nation whose trade must be considered small in comparison with that of this country, had yet been found so advantageous by other countries that in the extent of its use it had not only overtaken the inch system, which had been established for so long a period, but had rapidly passed it, and was now either used or being adopted by more than twice as large a population as that using the inch. The metre was thus fast ousting the inch; and whether this country assented to the change or not, there was no doubt that all the other civilised European nations would adopt the metre; and if England persisted in adhering to another standard, it would sooner or later be in an isolated position, differing from all the rest of the world.

While a broader view should therefore be taken of the subject than to confine the consideration of it to engineering work, he thought that even in this connection the metre would be found preferable to the inch, in consequence of the simple decimal relation which he had already mentioned as subsisting between the lengths and weights and other measures of the metre system. Thus a cubic metre of water weighed 1 tonne (1000 kilogrammes), and was also 1 kilolitre in capacity: and therefore if it were required to ascertain the weight of a mass of rock, measuring say 6 metres long by 3^{m} wide and 2^{m} deep, the product of these was 36, which would be the weight in tonnes and also the content in kilolitres of a vessel of water of those dimensions; and multiplying this again by the specific gravity of the rock would give at once the weight of the mass of rock of that size. The inch on the contrary had no simple decimal relation to the pound weight, and could have no such relation except by reconstructing the whole of the present tables of weights and measures, which would be better effected by the substitution of the complete metre system at once. He therefore strongly supported the adoption of the metre system in this country.

Mr. C. W. SIEMENS said he had paid some attention to the subject of the metre system, and had carried out a good deal of work in France with the metre scale, but had not found any inconvenience in working upon that system. His own draughtsmen

easily fell into the habit of working with the metre scale, and he had had frequent opportunities of watching its working in the hands of French workmen. There was one misconception frequently entertained in this country with regard to the metre, namely that as the metre was the basis of the system it must necessarily be taken as the unit of measure in all instances. This was not at all the case in France however, where, although the metre was the basis of the system, the millimetre was really the unit in mechanical engineering, and mechanical drawings were figured not in metres but in millimetres. He found the millimetre was a very convenient unit for setting out small mechanical work; for being equal to about 1-25th inch it was smaller than 1-16th inch and larger than 1-32nd inch, and was therefore just such a dimension as a workman could still readily appreciate in following a drawing. Of course the millimetre without further subdivision would not suffice to measure with such wonderful precision as was attained by Mr. Whitworth's system of contact measurement, which had been carried out in connection with the inch divided decimally. But for such accurate measurements the unit of measure employed was of little consequence, since any unit could be decimally subdivided to such an extent as to give the required degree of accuracy; and under the metre system the millimetre was subdivided for the very minutest descriptions of work into 100 parts called centièmes, each of which was equal to about 1-2500th inch, and was therefore as suitable for very small measurements as the thousandth of an inch.

Moreover independent of the metre being so convenient a measure for ordinary commercial purposes and already so extensively adopted, he thought it deserved serious consideration whether it would be wise to abandon altogether a measure of some such length as the yard or the metre, as would be the case if the inch were taken as the unit of measure. He agreed that in respect to its verification the metre was not an absolute length; but that was really not a matter of consequence, since, if the quadrant of the earth's circumference were measured a hundred times, each measurement would be likely to differ from all the rest; and if the measurement were taken several hundred years hence, perhaps the

earth itself would have slightly altered in size during that period. The verification of the metre was therefore dependent upon the accuracy of copying an original standard, just the same as in the case of verifying the inch; and this original standard would always be referred to, instead of measuring the quadrant of the earth over again. It was nevertheless of some importance that the unit of length should be a measure referable to the size of the earth, because it was then easily applied to geographical and even astronomical purposes; and in this respect the metre had an advantage as the unit of length, in being approximately an even decimal subdivision of the quadrant of the earth's circumference.

He concurred entirely in the desirability of having a system of measure in which there should be a direct decimal relation between lineal, square, and cubic measure, and between these and weight, as had been explained to be the case under the metre system. It had been correctly explained that the metre afforded a very great facility for ascertaining the weight of any bulk of material, its linear dimensions and specific gravity being known. There was then the least demand made upon the memory, since the specific gravity of different substances was all that had to be borne in mind, instead of a number of practical rules having to be recollected, which were applicable to one material only. The product of the cubic dimensions of any substance in metres multiplied by its specific gravity gave the weight of the substance in tonnes, being almost identical with English tons, or in kilogrammes when the decimal point had been shifted three places to the right. Upon the whole he considered it would be far better to adopt the metre system in this country, in accordance with the other nations who were already using it, than to decimalise a separate unit which would never work afterwards in harmony with the rest of the world.

Mr. James Heywood, as a member of the deputation from the International Decimal Association, said that in advocating the metre system before the British Association he had found the statistical section were generally in favour of the metre, but in the mechanical section there was more difference of opinion, and several engineers opposed the introduction of the metre system and

preferred the plan of taking the inch as the basis of measurement. He thought however the probability was that the public feeling of this country would ultimately decide in favour of the metre; because as England was connected with all the rest of the world by trade, it was greatly to her interest that any change should be in harmony with the custom of other great nations. The Anglo-Saxon people had not hitherto taken any decided step in the matter, whilst many of the continental nations had decidedly pronounced in favour of the metre, and its use was widely spread through all those countries. In the North American States however a commission had been appointed to consider the question. Adverting to one point of detail in the two systems, which had been urged on the side of the inch in the paper that had been read, he did not agree in thinking that 14·67 millimetres was a less convenient expression for a rifle bore than 577 thousandths of an inch; on the contrary he was of opinion that for a workman using such measurements it would be easier to take 14 millimetres with only two decimal places following than to take the whole in decimals of an inch to three places. He had been much struck with the observations of Mr. Tite at last year's meeting of the British Association at Bath, upon the results of his experience as an architect in large works on the continent in which the metre system was used: that system had proved so much more convenient in large calculations than the English system that he had always used it since, and recommended it very strongly as a matter of business, since the calculations were all in the decimal system and therefore made with less labour, and required a smaller number of clerks. In Germany there had been meetings of engineers and others practically interested in the public works of the country, and the reports represented them as almost unanimous in favour of the metre system. That system had been gradually working its way into Germany through the railways from France, which carried everything weighed in kilogrammes; and to avoid the trouble of weighing everything over again, the Germans had adopted the kilogramme, which weighed a little more than 2 lbs. The change to the new system was the great difficulty for this country; but the points of dissimilarity between the metre system and the present weights and

measures were not so serious, he thought, but that intelligent workmen would soon become accustomed to the new system; and for the population at large it must be introduced into the schools of the country, so that the next generation might be prepared for a complete change, as he believed the world was moving on in the direction of a universal adoption of the metre system.

Mr. J. Scott Russell remarked that, although he had a great preference for the existing standards of measurement in this country, he did not think that any change which was to be a great advantage and an important boon to the next generation ought to be opposed on the mere ground of its great inconvenience at the present time; and he considered the country at large was greatly indebted to the International Decimal Association for the manner in which they had brought the subject of decimal measurement and the metre system before the attention of the public. He believed that the decimal system would ultimately become universal; and if persuaded that the metre had a fair chance of becoming the universal standard of measure throughout Europe, he would be ready to incur the great inconvenience of making the transition from the present standards, in order to facilitate the transactions of the next generation. Many concurred in this sentiment, which he considered must be regarded as a very liberal concession on the part of mechanical engineers, because there was no other description of work whatever in which half so much trouble and inconvenience would be suffered from a change of measure as in mechanical engineering. No doubt the metre might be inconvenient for the more common transactions of other trades, but the change was a far more serious matter in engineering work, because it would utterly disarrange all the habits of thought of mechanical engineers, who might be said to carry the inch in their eye and to have the foot incorporated in their entire business operations as the existing standards of measure. Under such circumstances an alteration to a new standard involved a great sacrifice, which however he thought mechanical engineers were prepared to make if it could be shown that the metre system was inevitably coming in the next generation, that it would be a great national advantage, and that great good would be effected by

making the change as rapidly as possible. There certainly appeared probabilities of a universal standard of measure for Europe, and it seemed not unlikely that the standard would be the metre.

The metre system possessed unquestionably the great advantage which had been pointed out, of a direct decimal relation between the measurement of any bulk and the weight of that bulk, without requiring anything to be remembered beyond the specific gravity of the substance under consideration. In his own work of shipbuilding he had found that it would be a great help to all calculations connected with ships if there were a habit of thinking in some unit which bore an exact integral proportion to a ton of water: and it was the fault of the present inch and foot that neither of them gave any convenient factor in relation to a ton of water. For a ton of water consisted of 35·955 cubic feet, and the long decimal fraction was so inconvenient that he had been led to get rid of it in his experiments with models by adding so much salt to the water as should make it weigh exactly 35 cubic feet to the ton. It so happened that the water containing that amount of salt was a tolerably fair average of sea water; and he had made all his calculations in shipbuilding upon water of that description, on account of the convenience of the simple factor connecting cubic measure with tons. The metre had in this respect an advantage over the inch or foot, and he thought it was so great an advantage in practice for engineering and shipbuilding purposes, that although he agreed in the advantages of decimalising the inch for mechanical engineering work, he was opposed to adopting any system which would require all measures first to be reduced to inches and then to be transformed to the metre scale for comparison with the rest of Europe. The advantages of decimalising the inch however were limited to the class of work in which the inch was most largely involved as the unit; and he did not think it desirable to go further and attempt to extend the inch system so as to include the measurement of long distances, such as miles, since it was evidently impracticable to think of miles or similar long measurements in inches.

With regard to the manner in which a change to the metre should be effected, he entirely agreed in considering that the proper way was to have the metre system taught at once in all schools so that the next generation might be prepared for its general use, and to urge its simultaneous adoption in all the other European countries in which it was not at present used; and the sooner it could be carried out universally, the better would it be for all pursuits, since a state of transition was attended with many trials and inconveniences. In the meantime the decimal system should be employed as far as possible in connection with the existing weights and measures; and when the ultimate change came, he was confident mechanical engineers would be found ready to incur the great sacrifice which it would involve, in order that the succeeding generation might enjoy the full benefits of the perfect decimal system founded upon the metre.

Mr. Leone Levi, the Secretary of the International Decimal Association, said he had been present at numerous statistical meetings held during the past few years in the principal capitals of Europe, at which statistical information upon a variety of topics had been sent in from the different countries taking part in the meetings; but although the information so contributed was drawn up in the same tabular form in each case for the purpose of comparison, it was found that the differences in the weights and measures of the several countries caused as much trouble in reducing them to the same denominations as there would have been in compiling the tables afresh. The evil was so great that at the very first meeting, held in Brussels in 1853, it was resolved to recommend a uniform system of weights and measures as essential to the advancement of civilisation and international communication. As however this general recommendation produced no effect, a commission was appointed to report upon the weights and measures in the different countries of Europe, and their relative merits and defects; and the result was that at the international statistical meeting at Berlin in 1862 it was resolved to recommend the universal adoption of the metre system. In the same manner at the International Exhibitions both of 1851 and 1862, the jurors who examined the productions of

the different countries, in order to report which were the best and cheapest, found from the same cause that they could not arrive at any decided conclusion. The difficulties surrounding their duty from the differences in the weights and measures employed were so great that they could not help recommending that these differences should if possible be done away with.

Many of the considerations advanced in favour of the metre system were no doubt extraneous to mechanical engineering; but this branch of work could not be treated independently of other departments of industry, since the interests of the whole country were bound up together in the question. Discoveries in other countries in the various sciences, although known at once throughout the civilised world, were yet deprived at present of much of their practical value, from the difficulty experienced in this country in dealing with foreign weights and measures; and foreign men of science were similarly prevented from arriving at correct results, and if they attempted to reduce the English weights and measures into the metre system, great danger of mistakes was incurred and much valuable time wasted. The extent of the difficulty was moreover fully appreciated by Englishmen when they had occasion to travel abroad and by foreigners coming to this country. These and many other general considerations in connection with the subject were common to the whole world, and he thought they led to the inevitable conclusion that a universal system of weights and measures was an object well worth attaining, and therefore worth taking some trouble to attain. Other European nations had got over the difficulty of making the change to the metre system, and he was sure that England, with all the means of education that were at her command, would learn it more easily than any other country; so that the difficulty need not enter into the question at all, and the only matter to be considered was whether the metre system was good and the change desirable.

In originating the metre system, the French nation, who had the credit of practically introducing and establishing it, had scrupulously guarded it against any possible imputation of being merely a French scheme, started solely for the honour and advantage

of their own country. The unit that had been taken as the basis of the system was a natural unit, based upon one of the great dimensions of nature; and the nomenclature of the system had purposely been constructed upon Greek and Latin terms, in order that it might become equally the property of all the nations in the world. Moreover the French academicians engaged in constructing the system had invited the aid and co-operation of a scientific commission from England, in order that there might be no ground for any national prejudice. He therefore thought this question, standing as it did upon a broad enlightened and international basis, well deserved the careful consideration of the English nation.

Mr. J. FERNIE thought that, in regard to the estimate given in the paper of the population in favour of the metre or the inch, the Indian empire might properly be taken on the side of the inch, on account of the very large quantity of machinery that was sent out there from this country, which was all constructed upon the basis of the inch. The apparent preponderance of numbers in favour of the metre appeared to be obtained by including countries which at most could only be said to be aiming at the metre; and he thought these could scarcely be admitted into comparison with the countries which might be claimed as having the inch in actual use. The reason why so many other countries had readily accepted the metre system was he believed because they had previously no system at all, and were therefore glad to avail themselves of a complete system which was offered ready made for their use. But this was not the case with England, in which was already established a complete decimal system of subdivision based upon the inch; and as the recent act of parliament had legalised the use of the present weights and measures decimalised, he did not see his way to the adoption of a universal system based upon the metre. As to the metre itself being a natural unit, he had shown in the paper that its supposed advantage in that respect was destroyed by the spheroidal shape of the earth; and the only natural standard that would have the advantage of being a single or unique dimension was the polar axis of the earth, which had already been suggested for the purpose. He was very glad to have had an opportunity of hearing the views

entertained by the advocates of the metre system, who had communicated much useful information upon the subject; and it was only by a full discussion of the question in this manner that the desideratum of a universal standard unit of decimal measure could ultimately be arrived at.

The PRESIDENT thought one of the greatest and most immediate objections to the adoption of the metre system in connection with engineering work was the great expense which would attend carrying it out; and he did not think a proper estimate could be formed at present of the cost that would be incurred. Otherwise he had found those to whom he had spoken on the subject were favourable to the adoption of a decimal system; and he believed that, if the thorough utility of the metre system was made clear to the mechanical engineers, they would in general be most willing to adopt it.

He proposed a vote of thanks to Mr. Fernie for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Eighteenth Anniversary of the Institution.

PROCEEDINGS.

4 MAY, 1865.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 4th May, 1865; FREDERICK J. BRAMWELL, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

WILLIAM DANIEL ALLEN,	Sheffield.
JOHN BAILEY,	Dublin.
WILLIAM BARCLAY,	Inverness.
WALTER BROCK,	Glasgow.
HENRY LEE CORLETT,	Dublin.
ABRAHAM DARBY,	Ebbw Vale.
BENJAMIN DOBSON,	Bolton.
WALTER ELLIOT,	Gibraltar.
WILLIAM DUNN GAINSFORD,	Sheffield.
WILLIAM GIBBS,	Wolverhampton.
DAVID GREIG,	Leeds.
WILLIAM DAKIN GRIMSHAW,	Birmingham.
HENRY HYDE, R.E.,	Calcutta.
JOHN JACKSON,	Alderney.
JOSEPH LEDGER,	Workington.
FREDERICK ALLEN LEIGH,	Manchester.
FRANCIS CARR MARSHALL,	Jarrow.
ROBERT MORTON,	Stockton-on-Tees.

William Mallabey Murdock, . .	Northampton.
Alexander Parkes, . . .	Birmingham.
William Perry, ...	Wednesbury.
Job Richards, ...	Smethwick.
John Richardson, ...	Gloucester.
William Mander Sparrow, . .	Wolverhampton.
William Stroudley, ...	Glasgow.
Edward Williams, . . .	Dowlais.
Solomon Woodall, ...	Dudley.

GRADUATE.

Edward Edwards Hewett, . .	Derby.

The following paper was then read:—

ON THE APPLICATION OF STEAM POWER TO CULTIVATION.

By the late Mr. JOHN FOWLER, and Mr. DAVID GREIG, of Leeds.

In a paper on this subject read by Mr. Fowler at a former meeting of the Institution on 29th April 1857 (see Proceedings Inst. M. E. 1857, page 57), reference was made to the Draining Plough, first drawn by horse power and afterwards by steam, and to the course of experience that the writer had with that implement, which had led him step by step to the application of steam power to the ordinary purposes of cultivation. In that paper the results of his experience were given for the previous seven years, during which this work had been developed; and in the present paper the subject is proposed to be continued by the results of his subsequent experience in carrying out the application of steam power to cultivation during the last eight years. This paper, which was left unfinished at the time of Mr. Fowler's recent death, has been completed by Mr. David Greig, who had been long associated with him in carrying out Steam Cultivation.

In considering the mechanical problem to be solved in the application of steam power to agriculture, it is requisite before referring to the design of any particular machine to examine the general principles on which the application of mechanical power to cultivation can best be effected. To do this effectually it is necessary to ascertain the nature and extent of the difficulties to be overcome; and these may be stated to be the following:—

I. The irregularities of level in the surface to be acted upon.

II. The varying positions of the machinery upon the ground, rendered necessary as the work proceeds.

III. The difficulty of getting heavy engines of sufficient strength moved about where no roads exist.

IV. The production of a rope of sufficient strength, hardness and elasticity to stand the work.

V. The changes in the state of the soil from the effects of weather.

I.—First with regard to the irregularities of level in the surface of the land to be cultivated.

The first idea which naturally occurs in applying steam power is that of attaching the motive power direct to the implement, as is done in the case of horses. But experience has proved that the power required to move a steam engine over the land, of sufficient power and weight for traction purposes, is quite impracticable, from the fact that such an engine would weigh at least 12 tons, and would in many cases absorb as much as 30 horse power in the mere act of moving itself at the rate of 2½ miles per hour. Moreover when the land gets at all wet and greasy on the top, it becomes quite impossible to make such an engine travel over the soil. Also the compression caused by its travelling over the land would in most cases neutralise the good otherwise effected by the cultivating implement; so that any advantage which there might be in direct action would be more than counterbalanced by the practical difficulties that stand in the way of its adoption.

Under these circumstances it becomes absolutely necessary to convey the power over the surface of the land by means of a rope, allowing the prime mover to stand in the most direct position for its work and exert all its force in accomplishing the operation to be performed. The employment of wire rope for this purpose was at first attended with considerable drawbacks, both from the difficulty involved in the application itself, and from the wear of the rope; the latter was chiefly caused by the amount of friction the rope was exposed to, which involved also a loss of power.

The use of wire rope in the cultivation of the soil was gradually developed from its commencement to its present successful application. The First system of using rope was by placing the engine in a stationary position at the side or corner of the field to be cultivated, as shown in the diagram Fig. 1, Plate 1, and leading the rope all round

the margin of the field; the two ends of the rope were attached to two winding drums at the engine, giving out and taking in the rope alternately, and the plough or cultivating implement being attached to the middle of the rope was hauled backwards and forwards across the field. This rectangular arrangement involved a great deal of fixing of machinery in the field before commencing operations, including fixing the engine and windlass, fixing a pulley or snatch-block at each of the two corners of the field nearest to the engine, and a large number of rope porters or carrying pulleys; it also entailed two moveable anchors, one at each end of the line of traverse of the implement, which had to be shifted by some means each time that the traverse was reversed, so as to lead the implement into a fresh line. The general construction of the Rope Porters is shown in Figs. 5 to 10, Plate 5: Figs. 5 to 7 show the larger kind used for the permanent lines of rope; and Figs. 8 to 10 show the small porters for the rope attached to the implement, which are withdrawn and placed again by boys as the implement passes across the field. In employing such an arrangement of tackle, the consideration of the complication of the parts, the numerous pulleys and frequent bending of the rope over the pulleys, which were of necessity small in diameter, and the great time required for fixing the apparatus, early led the writer to the conclusion that such a plan of applying power could not prove permanently successful; and although it has been extensively used it is now generally superseded by more direct and simple arrangements.

The Second mode of using wire rope, shown in Fig. 2, Plate 2, was merely a modification of the first, and consisted in placing the stationary engine and windlass in the centre of one side of the field, and leading the ropes away diagonally across the field to two moveable anchors placed at each end of the line of traverse of the implement. A pair of horizontal leading pulleys attached to the windlass allowed the rope to pass off at the varying angles which the progress of the work required, until both the moveable anchors came in a straight line with the windlass. By this triangular plan the two fixed pulleys in the corners of the field in Fig. 1 were dispensed with, and fully one fourth of the rope with its requisite porters was

saved. This arrangement was a great improvement on the former, and the encouragement that it elicited led to a further step, which suggested the important principle on which all subsequent machines have been constructed, namely that of direct pull.

The Third plan of working with rope, with direct pull upon the implement, is shown in Fig. 3, Plate 3, and consisted in placing two horizontal winding drums under a travelling engine, which moved slowly along the headland of the field, keeping always in line with the work. The travelling motion was obtained by means of a pinion gearing into a large internal toothed wheel fixed upon one of the carrying wheels of the engine, and connected to it by a friction clip to prevent any risk of injury from overstrain. The rope was stretched from one winding drum of the engine across the field to a moveable anchor on the opposite headland, and then back to the implement, to which it was attached; and another rope from the other drum was also attached to the implement. The work was performed by the engine winding up one drum as it gave off rope from the other, the implement being thereby pulled backwards and forwards across the field.

The Moveable Anchor is shown in Figs. 11 and 12, Plate 6, and consisted of a carriage with a horizontal pulley A mounted on it, round which the hauling rope B of the plough worked, while the sharp-edged carrying wheels C entered the ground and resisted the side pull of the rope. The anchor carriage was moved forward each time of changing the direction of the implement by means of a stationary rope D stretched along the headland and made fast at the end, as shown in Fig. 3. This rope was attached to a small drum E on the anchor carriage, and a slow motion was communicated to the drum from the pulley A by the two pair of wheels and pinions F being thrown into gear; the anchor carriage thus pulled itself along the headland a sufficient distance each time, so as always to keep in line with the implement and engine. The box G on the carriage was weighted sufficiently to serve as a counterpoise to the pull.

The experience gained in this plan of working showed that the principle of direct pull of the engine upon the implement was the correct one; but the cumbersome arrangement of the two winding

drums, and the difficulty of coiling the whole length of rope required for reaching across the field, together with the crushing of the rope arising from the soft material of which it was then made and the small diameter of the drums necessarily employed, indicated the need for a still further modification in the apparatus.

The next step was the employment of an Endless Rope, stretched across the field as in the preceding case; with this difference, that the power was now communicated to the rope by friction, instead of by winding on and off a drum as in the plan last described.

In order to secure such an amount of hold on the rope as to give sufficient pull, it was found necessary to employ two driving drums with four grooves each, as shown at AA in Figs. 13 and 14, Plate 7; and the rope was led four times half round both drums, as represented in the diagram Fig. 14, the two drums being geared together by the pinion B. By this means sufficient hold was obtained to overcome the resistance of the work. In order to meet the variations in the length of the rope occasioned by the irregularities in the boundary of the field, two light barrels worked by hand were mounted on the cultivating implement, to which both ends of the rope were attached, and by these barrels a portion of rope was let out or taken up by hand as required to keep it at the proper degree of tightness. When new, this apparatus worked very well; but the wear and tear of the rope from its numerous bends, and more especially from another cause which required some time to develop itself, rendered it necessary to abandon the plan. This great difficulty was the impossibility of keeping the eight grooves in the driving drums all of equal diameter. The two leading grooves were found to be always wearing at double the rate of the others; and all the grooves having to revolve at the same rate, a constant surging of the rope was occasioned by the difference in speed of the circumference of the different grooves. This involved destructive wear of the rope and loss from friction, and every revolution of the drums caused a further grinding away, thus increasing the errors in the diameters of the grooves. As an instance of the deterioration thus occasioned, it may be mentioned that the apparatus got into so bad a condition

that the engine could not perform one half of the work which was done by it when new.

These evils led to a modification of this plan of driving, by the employment of a single driving drum with two V grooves, as shown at C in Figs. 15 and 16, Plate 7, round which the rope was made to take two three-quarter turns, one in each groove. This was effected by using two guide pulleys DD, one on each side of the driving drum C, which transferred the rope from one groove to the other of the driving drum. In this case, as there was only one driving drum with two grooves in it, instead of two drums with four grooves in each drum, the wear and tear was greatly diminished; and this plan of apparatus, although retaining to some extent the evils of the former, is still working successfully in several places.

The objections still remaining however are the number of bends to which the rope is subjected; and from the grip on the rope being obtained by its forcing itself into the V groove by the tension put upon it, serious wear and tear result. In this case there is a compound surging; for from the point where the rope first touches the drum the pressure forcing the rope into the groove increases as the rope passes round the drum, causing the rope to lie deeper in the groove, whereby it virtually lessens the diameter of the drum; in consequence of which the rope must keep on surging endways at the same time that it sinks deeper into the groove. Although these movements are so small as to be imperceptible to the eye, they are actually taking place continually; and the result is serious wear and tear, from the constant grinding motion over the whole rope in succession.

At this point a mechanical contrivance came to the writer's aid, by which a sufficient bite can be obtained with only one half turn of the rope round the driving drum, whilst the rope is taken hold of in such a manner as to cause no friction or surging whatever. At the same time also the total number of bends of the rope is reduced from five to two, as there is only a single bend at each end of the field, which causes a most important saving in driving power and wear and tear. By this mechanical appliance the rope

was at once enabled to perform double the amount of work that it could with the previous apparatus.

The very ingenious contrivance by which this is effected is termed the Clip Drum, and is shown in Figs. 17 and 18, Plate 8, and in detail to a larger scale in Figs. 19 to 24, Plate 9. It consists of a series of pairs of jaws or clips A and B, hinged round the circumference of the drum close together in a continuous line, forming a complete groove in which the rope C works. Each pair of clips in succession, as it passes round to the point where the pressure of the rope upon the drum commences, closes and seizes hold of the rope, as shown in Fig. 20; and continues to grip the rope throughout the half revolution until reaching the point where the rope begins to leave the drum, when the clips fall open, as shown in Fig. 21, being relieved from the pressure of the rope. The amount of grip is in all cases proportionate to the pull upon the rope, and such as effectually to prevent any slipping.

The only provision requisite to suit the clip drum for working with any size of rope is to adjust the width of opening of the clips to the particular diameter of rope to be driven, by widening or contracting the distance between the centres of motion of each row of clips. This adjustment is effected in a very simple and complete manner by having the lower row of clips B centred upon a ring D, Figs. 20 and 21, which forms the circumference of one half the depth of the drum; and this ring is screwed upon the body of the drum by a thread chased round its entire circumference, so that by turning the ring round in either direction the distance between the centres of the upper and lower clips is simultaneously increased or diminished in every pair to exactly the same extent, all of them being kept in perfectly parallel positions. The ring D is held in the desired position by the bolt E, Fig. 21, which prevents it from turning.

The lower clip B of each pair, having a heavy overhanging lip F on the outside, is enabled to lift the upper clip A by means of a small finger G projecting from its inner end and pressing upon the tail of the upper clip; so that the clips always remain open until receiving the pressure of the rope, and they fall open again

and release the rope the moment that the pressure is withdrawn. The stop H on the upper clip coming in contact with the body of the drum prevents the clips from falling open too far. Figs. 22 to 24 show the bolts that serve as keeps for holding the ends of the pins on which the clips are centred.

The action of the clips is thus just similar to the closing of a hand upon the rope, laying hold at once so firmly that the rope cannot slip, and retaining this hold uniformly until the rope is released altogether by the opening of the clips; so that all friction or surging from an imperfect hold is avoided, as well as any shifting of the rope at the beginning and end of its contact with the drum, such as is inevitably the case in round or V grooves. At the same time by means of the ring D on which the lower row of clips are centred, the hold upon the rope can be adjusted to any desired amount according to the power required to be transmitted; and it can be absolutely depended upon, when once adjusted, to continue working uniformly with the same amount of hold.

An important practical advantage found to result from the working of this clip drum is that the rope is subjected to a continual pressure upon its sides whilst passing round the driving drum, thus avoiding all tendency to the rope being flattened by the pull, as in an ordinary round-bottomed groove where the pressure of the rope is upon the bottom of the groove only. Also the groove in the clips being so curved as to fit the rope closely round a considerable portion of its circumference, the pressure preserves the form of the rope and serves to consolidate it, by continually closing down all protruding wires and preventing the deterioration of the rope by such parts being caught in passing the subsequent guide pulleys. In the working of this apparatus it will be seen from Fig. 3 that one half of the total length of rope is never in contact with the driving drum, the other half alone being passed round it backwards and forwards successively; and in many cases the actual result has been that the portion of the rope which passes round the drum and has all the work to do of transmitting the hauling power has lasted longer than the other portion which has no such work to do but is simply exposed to the bend round the

pulley of the moveable anchor on the opposite headland, the friction from the guide pulleys being exactly the same in both cases. Another important advantage is that no tension is required upon the rope leaving the drum; all that is requisite is that the rope be taken away and not allowed to kink.

It may be remarked here that these advantages of the clip drum render it specially adapted for use in other positions where a rope is the medium of conveying power; and the saving that it has effected in the wear and tear of the rope employed in cultivation has been fully corroborated by the result obtained in its use for other purposes. It is believed that the action of the clip drum is mechanically correct, and that it will be found highly advantageous for general application in transmitting power by means of ropes.

II.—The second point of difficulty for consideration is the continually varying positions of the machinery upon the ground, rendered necessary as the work proceeds; in consequence of which it is necessary for some means to be provided whereby the ropes will admit of the two extreme points being moved nearer together or further apart as the varying boundary of the fields may require. With a pair of winding drums this is easily effected by not allowing the unwinding drum to begin giving off rope until the rope becomes tight in each case. For this purpose a heavy break has to be applied to the paying-out drum to save the rope from trailing on the ground; for if the rope is not kept from touching the ground a serious loss of power is the result, as the difference in draught required to pull a rope lying on the ground and one properly carried is as much as ten to one. Hence it becomes a very important point that the rope should be efficiently carried off the ground, and this is a matter to which the writer has given considerable attention.

Figs. 25 and 26, Plate 10, show the construction of the Compensating Break that is employed when a pair of winding drums are used, so as to compensate for changes in the length of rope that is required as the work proceeds. The winding drum A

is driven by the pinion B, which is coupled to the driving shaft C by the clutch D; but the driving shaft is geared to the paying-out drum E by means of the second shaft F having corresponding pinions at each end, so as to allow the two drums to run in opposite directions. The two pinion shafts C and F are however made to revolve at slightly different speeds, by the two outside pinions G and H that gear together being of different size, the pinion H being 1-9th smaller than the other; and consequently the paying-out drum E is compelled to revolve 1-9th slower than the winding drum A. This causes the slack in the rope to be all taken up by a few revolutions of the drums; and further strain on the rope is prevented by the pinion G being connected to its shaft by a friction break I, so that it is allowed to slip on the shaft. The rope is thus kept constantly stretched tight by the friction of the break I.

When the endless rope and clip drum are employed for working the implement, instead of two winding drums, a very ingenious and efficient plan has now been adopted, whereby the rope is kept tight without any loss of power; the slack of the rope is taken up or more rope is given off as the field may require, and the implement cannot be started until the rope is tight. This is effected by means of what is termed the Slack Gear, which is shown in Figs. 27 to 30, Plate 11. It consists of two small barrels A and B mounted on the plough, and connected by gearing with a relative speed of five to one, so that the pulling rope C in drawing off 1 foot length of rope from the barrel A winds up 5 feet of the slack rope D on the other barrel B, until all the slack is taken up. The implement then starts at once when the rope becomes tight, and on its arrival at the other end of the field the act of the man taking his seat at the other end of the implement reverses the action of the barrels, so that what was the slack-rope barrel B becomes the pulling one and *vice versâ*. The driving of the barrels A and B is effected by a pitch chain E, which passes over a wheel F of large diameter on the pulling barrel A and over another G of one fifth the diameter on the slack barrel B; a second chain H being placed on the opposite side of the barrels, working over a pair of wheels of corresponding sizes to the former but reversed in their relative positions. The self-acting levers and

clutches I and J are both kept in gear by springs, but are thrown out of gear alternately by the act of the man taking his seat upon the seat K, Figs. 27 and 28, first at one end and then at the opposite end of the plough, and by that means pulling the rod L or M. The same action is thus obtained in whichever direction the implement is travelling, one of the chains E or H with its pair of driving wheels being always in gear with the rope barrels, whilst the other is out of gear.

The effect of this slack gear is to maintain under all circumstances a ratio of five to one between the tension of the pulling rope and that of the slack rope; and consequently whenever the working distance between the engine and the moveable anchor is diminished by the field narrowing, whereby the tension on the slack rope is diminished, this is simultaneously compensated for by the pulling barrel A causing the slack barrel B to wind up the slack rope until its tension is brought up to the fixed ratio of 1-5th of that of the pulling rope. In the opposite case, when the tension of the slack rope is increased above that ratio, owing to the working distance being increased by the field widening, the slack barrel B unwinds until the proportion is restored; and as the pulling barrel A winds up at the same time at 1-5th the rate of the slack barrel unwinding, the implement is propelled forwards to that extent in excess of the direct pull of the engine upon it. The object is thus attained of keeping the rope constantly tight, so as to carry it clear of the ground, however great or sudden may be the variations in its working length caused by the irregularities in the outline of the field; and this is effected entirely by self-acting means without any attention being required on the part of the man and without any loss of power. An advantage arising from the use of the slack gear is the elasticity thereby afforded to the rope, should the progress of the implement be obstructed by its coming in contact with stones or roots in the ground; in this case the rope not being absolutely tight has a margin for taking up further slack, which acts as a spring, easing the strain caused by stopping the implement suddenly.

III.—The third difficulty to be considered is that of getting heavy engines of sufficient strength moved about over the ground where no roads exist.

This has been a serious drawback to the introduction of steam cultivation, and one which has led to more breakage of tackle and machinery than all the action of the machinery in performing its work of cultivation. Two causes have contributed to this result: namely, a mistaken idea at first prevailing that lightness was an essential point, which led to paring down the metal in all parts of the machinery; instead of making the machinery so strong that it could not be broken by the full steam power, and then increasing the width of the carrying wheels to such an extent as to ensure carrying the engine over the wettest fields. The other mistake was that the speed of working on the road wheel was not reduced sufficiently, so as to allow the engine sufficient leverage to get out of any difficulty that it might happen to get into; and the want of judgment on the part of the men using these machines often led to their being put in places of quite unnecessary difficulty.

The first of these mistakes has now been met by making the machinery so strong that the steam when full on is the weakest part of the whole machine. This has naturally led to great weight; but that is no real obstacle, provided the carrying power of the wheels is increased in proportion to the increase of the weight to be carried. In fact the weight is an advantage in steadiness for working, so long as the machine can be kept from sinking too much into the ground. Carrying wheels are now being made for special circumstances as much as 30 inches wide on the rim, as shown in Fig. 31, Plate 12, where the dotted lines A A show the portion that is added to the ordinary 20 inch wheels B B; and these wheels have been proved to carry a 12 ton engine over any land in a fit state of cultivation. The wheels are driven each separately by means of a friction clip C, which prevents any risk of breakage from excessive strain of driving, the shaft D being driven by the pinion and spur wheel E.

The next point was to reduce the speed on the driving wheel so as to give the engine sufficient leverage to get out of any

difficulty; and for this purpose two different driving speeds are provided, one giving $2\frac{1}{2}$ miles per hour and the other only 1 mile per hour for travelling, when the engine is working at its full speed of 140 revolutions per minute. In order to obtain sufficient adhesion under specially difficult circumstances for the exertion of the full tractive power of the engine, the additional provision has been made of temporarily fixing transverse T irons by means of bolts upon the rims of the wheels, as shown in Figs. 31 and 32, Plate 12. With regard to the men, time and experience combined with the extra work caused to them by getting into difficulties are the means of gradually reducing the difficulty arising from want of judgment on their part.

Another plan for meeting the difficulty of getting such heavy machines moved about has been adopted with the most satisfactory results. This consists in combining the power of two small-sized engines, as shown in Fig. 4, Plate 4, the second engine being worked in place of the moveable anchor in the previous plan of working shown in Fig. 3. Each engine is provided with a clip drum, which is essential to carrying out this system of cultivation; and the rope is worked as an endless rope between the two engines by having both its ends attached to the cultivating implement. As the power of both engines is applied at the same time to the rope in each direction, the heaviest class of operations can be performed by them; and the loss of power in working the rope is very much lessened by the fact that both lines of rope are always in effective tension, and are thereby well carried with half the number of rope porters. Another advantage derived from the adoption of this plan is that the engines are better adapted for the other work of the farm, as the farmer has then two engines of 7 or 8 horse power instead of one engine of 10 or 14 horse power; and by having two of them a regular system of cartage on the farm can be carried on, the engines being specially arranged for traction purposes.

IV.—The fourth difficulty to be surmounted was the production of a rope of sufficient strength and hardness, combined with

elasticity, to stand the required work; and this was a very serious point, as the inability to accomplish it nearly upset at one time the profitable employment of steam cultivation.

The first rope used was made of iron wire; but it was worn out so quickly, not doing so much as 200 acres, that it soon became evident such material would not stand the strain and friction attending the work; whilst by increasing the strength of the rope its weight was so much increased as to consume nearly the whole engine power in overcoming its friction. These difficulties became so serious that great exertions were made to get a rope of steel sufficiently hard to stand the wear of trailing on the ground and also the friction caused by coming in contact with the numerous pulleys of the machinery then employed; and in 1857 two steel ropes were applied which answered the purpose admirably, and performed with the then imperfect machinery upwards of three times the amount of work that was done by the first iron rope. From this point it was established undoubtedly that all risk of the difficulty with the rope causing a check to the application of steam to cultivation was now safely overcome, the introduction of the steel rope having effectually accomplished the object in view. The machinery for working the rope however required great improvement and alteration, before getting to the point of thorough efficiency with a minimum of wear: the chief objects in these improvements being to have as few bends as possible, and those bends over large pulleys. A great saving in the wear of rope has also been effected by the improved means of keeping the rope tight, preventing it from dragging upon the ground. From time to time, as the various improvements in the machinery have been effected, the increased quantity of work done by the rope before being worn out has been very marked; so that the cultivation of from 2000 to 4000 acres can now be accomplished with one steel rope, the amount varying with the nature of the soil and the width of the implement used.

Although much of this increase of duty depends upon the construction of the machinery, still a great part of the success is to be attributed to the superior manufacture of the steel wire. At

first the steel ropes, although much superior to those of iron wire, were very irregular in their quality and durability, often varying as much as one half in these respects; and up to the present day steel ropes made of the common qualities of steel wire vary in their quality to the same extent. After a series of careful experiments combined with accurate testing, a quality of wire has now been produced for the purpose, which can be obtained of complete uniformity in tensile strength, and possessing a high degree of hardness, combined with the requisite flexibility and toughness for working. To this great advance in the manufacture of steel wire rope is to be attributed in a great measure the present success of steam cultivation. The tensile strength of this wire has been increased from 1500 lbs. to in some cases 2400 lbs. for No. 14 wire gauge. Steel wire of the common sort has indeed been made to attain nearly the same tensile strength, but this is always accompanied by the defect of brittleness, which is a fatal defect in the working of a wire rope. If the quality of steel rope should continue to improve at the same rate as during the last three years, the cost of wire rope will be reduced to an unimportant item per acre.

At the commencement of steam cultivation the iron wire rope ran a mileage of not over 750 miles before being worn out, costing 1*s.* 7*d.* per mile of running. The first steel rope ran 1800 miles, costing 1*s.* per mile; and the present steel ropes are running on an average 9000 miles, costing only about 2¼*d.* per mile, running with a tension upon them of about 25 cwts., and this notwithstanding that the price of rope has been increased from £60 to £84 for the ordinary length of rope of 800 yards. The steel rope at present used in steam cultivation is 11-16ths inch diameter, and weighs about 2 lbs. per yard, making a total of about 14 cwts. for the length of 800 yards.

V.—The fifth class of difficulties are those arising from variations in the state of the soil caused by the effects of the weather.

These difficulties have been principally felt in wet weather, in moving the engine, and also from the stickiness of some land when in a half wet state, which is too often the condition of the land whilst being cultivated. In such cases all the tackle would become

literally covered with clay, and the power required to move the rope and the machine would be very great. This difficulty should not indeed exist, as no land ought to be touched when in such a state; but clay land has hitherto very often been worked when wet, from want of sufficient force to get all the work done before the wet sets in, and also from the inability of horses to perform the work while the land is in a dry state. As an illustration may be taken a clay land field ploughed by horses while very wet, after which if the next year be dry it will be literally impossible to work the same ground with horses until some rain comes to soften it, as the horses' shoulders and the implement would not be able to stand such jarring work.

With steam power however there is no difficulty in working the land in the driest condition, which is the proper time for such work; and if this is strictly attended to, it will never get into an extremely hard state. Supposing the clay land is ploughed wet by steam power, more power will be expended in pulling the dirty rope and the sinking plough than even if the land be so dry that the soil breaks up into large pieces of as much as 1 cwt. each, though the latter could not be the case but for the wet-kneading that the land received before by being ploughed wet by horses. If the farmer were only to keep his machine off the land in wet weather, and work it night and day in dry weather, he would see the great advantage that would accrue from working at the proper time. In fact the principle of the old maxim, "make hay while the sun shines," applies to cultivation of the land as well as to hay.

Another system of steam cultivation has been adopted to meet special circumstances, by the use of two large engines, each of which is supplied with a winding drum, instead of the clip drum and endless rope employed with the light engines in the plan last described and shown in Fig. 4, Plate 4. The two large engines are placed at opposite ends of the field, the same as in Fig. 4, but they act alternately instead of in combination, one pulling the plough in one direction while the other moves forward into position for the return bout, and *vice versâ*.

In order to make the rope coil in a regular manner upon the winding drums of the engines, an arrangement of self-acting Coiling Gear is employed, which is shown in Figs. 33 and 34, Plate 13. It consists of a pair of guide rollers AA, between which the rope passes when coiling on or off the large winding drum B. These guide rollers are carried at the end of an arm C, which is centred at the other end upon a bracket D carried loosely upon the centre spindle E round which the drum revolves. The arm C has a stud fixed in it at F, working in a spiral groove G formed on the lower part of the spur wheel H, which also turns loosely round the centre spindle E. A second spur wheel I is carried close above the wheel H, and is fixed upon the upper end of a cylindrical casing carried up from the bracket D and passing through the wheel H. A pinion J carried by a stud fixed in the winding drum B gears into both the wheels H and I, but the upper wheel I has one tooth more than the lower one H; and consequently in each revolution of the winding drum the pinion J being also carried round with the drum causes the lower wheel H to be advanced one tooth, the upper wheel I being held stationary by the arm C, which is held at the outer end by the tight stretched rope passing through the guide rollers A. The spiral groove G is thus gradually turned round, and acting upon the stud F in the arm C causes this arm with its guide rollers A to be gradually raised and lowered, thereby guiding the rope from top to bottom of the drum in regular coils whilst it is being wound on or off the drum.

The purpose for which this system of working with two large engines was arranged was for travelling about and doing work by hire, so as to meet the requirements of those who have not sufficient land or capital to purchase machinery for their own use. The plan has the advantage of requiring no fixing, and the machines are ready to start work the moment they get into the field; and as soon as the implement stops, the ropes are in their places and the machines ready for removal. As fields of all shapes are met with, it is of importance that the machines should be of such a character that no loss of time should be occasioned by the management of the rope. So far as the working of these machines goes, it is entirely

satisfactory, but the first drawback to the adoption of this plan is the price. Secondly there is the difficulty of taking two large engines about; and from the fact that a heavy break has to be put on the paying-out drum in order to keep the rope tight, considerable power is lost. But still the time saved in doing small irregular fields more than counterbalances those disadvantages.

The traction part of the machinery having now been considered, the most mechanical means of performing steam cultivation has to be referred to.

The implements hitherto used for steam cultivation have been something similar to those employed with horse power; but recently a system has been arranged for throwing up the land in the roughest possible way, and leaving it in such a state as to expose the largest amount of surface to be acted on by the air, which is the only truly practical way of dealing with heavy land. The development of different classes of implements will always be going on, to meet different varieties of land and the various operations which will ultimately be required. It is proposed here only to refer to the best principle of loosening the land for the purposes of cultivation, looking at the question entirely from a mechanical point of view.

Cultivation by rotary implements has been much advocated, and may appear at the first glance the right means of applying steam power: but when the nature of the substance to be dealt with is considered, this plan is mechanically wrong in the way of operating on the soil, from the fact that rotary implements must necessarily strike on the top of the hard land, thus absorbing a quantity of power in entering the hard substance. As an illustration of this, reference may be made to the method adopted in breaking up a macadamised road: the pick is used so as to lever the material upwards, and by entering it underneath the hard substance the latter is easily broken up. A rotary digger must however be used in the contrary way, or else it will be acting against the onward motion of the machine, thereby increasing the power required for

traction. The difficulties that interfere with getting such a machine over the surface of the land have also to be considered, and the damage done to the land by the transit of such a heavy machine over the soil to be cultivated; and these objections, with the serious error in the mode of applying the power, must prevent such a system from proving practically successful.

The cultivation of the land consists merely in loosening a certain quantity of soil, and what has to be considered is how to loosen the greatest quantity with the smallest amount of power. In all the experiments tried by the writer it has been found that this is never so economically done as by wedging the soil off to a loose side, and entering the wedge underneath, where the soil is softer. Much objection has been raised to the old mode of working with the plough; but in the writer's opinion it is not the implement that is at fault in that case, but the power that is defective; and by the aid of steam that implement can now be driven at such a pace as to throw the land sideways in a manner quite equal to the effect of any digging by hand. The writer does not advocate any particular shape of mouldboards or tynes, nor the formation of a "furrow slice" as it is termed; all that is wished to be accomplished is to pitch the earth sideways, as in digging, and the shape of the tool must be such as to effect this in the best way. The great point requiring attention is that the tools should be so arranged that each follows its neighbour, taking its own cut and wedging off the soil to a loose side. If this is done, the speed of $2\frac{1}{2}$ miles per hour at which the implement is driven will throw the loosened material at least 2 feet clear from its previous position, and by the rapid motion it will be left in the state most desirable to the farmer and in the best possible condition to receive the action of the atmosphere, and this will be effected with the least amount of power. Few implements embody this principle; but without it there is a great loss of power, which is accounted for by the fact that a tyne or cutter in making its way through the solid ground always takes twice the power to draw it that would be required if it were taking its cut close to where another cut had been taken before. This is a point of great importance and should never be lost sight of in the

construction of implements for heavy work. In the implements for light operations it is by no means so necessary; but still the principle holds good to a certain extent and should be attended to as far as practicable.

In order that steam cultivation may be brought to the greatest perfection, it is of the utmost importance that the use of horses in cultivation should be altogether abandoned. For this purpose a number of implements are required, adapted to get over a large breadth of land in a day, so as to do the very light operations of the farm and exclude horses entirely from such work, as their use inevitably increases the expense of after operations, besides being detrimental to the land. If the horses on a farm are done away with altogether or as far as practicable, the cartage becomes the next question to be dealt with; and before steam cultivation takes its proper place, the heavy part of the cartage must be done by the ploughing engines. Considering however that to be good ploughing engines they must be good traction engines, there is nothing to stand in the way of cartage by steam power but the want of good roads about the farm, which are an essential point in a highly cultivated farm, whether steam cultivation be employed or not. The experience lately gained in the use of the traction engine is that loads can be conveyed over moderately good roads at an expense of 2*d.* per ton per mile; and there is therefore no doubt that the farm cartage can also be done economically. This operation will require some time to develop itself, as the vehicles for conveying the materials will have to be bought and proper roads made in every direction through the farm before steam cartage can be carried on conveniently; but at present there can be no reason why all corn should not be taken to market and coals and so forth brought back by steam power. The writer has no doubt that before ten years' time two thirds of the cartage of the farm will be generally done by steam, and also that the railways will be fed by traction engines, and that these will become quite common: although, through mistaken ideas, serious attempts have been made to stop their use on the public roads. A 10 horse engine will convey a load of 20 tons independent of itself over a road with

gradients not exceeding 1 in 15; and the wear and tear is very slight indeed in properly constructed traction engines.

In order properly to understand the advantages of steam cultivation, it is necessary to draw a contrast between steam power and horse power as applied to cultivation.

In the case of horses, the utmost available force which can possibly be brought to bear on an implement is 9 cwts., and this is obtained by employing six horses, or two more than can work profitably together on the land. The practical limit of draught is therefore 6 cwts., as horses cannot give off the same amount of draught in the fields as on hard roads. Hence with a team of four horses giving off 6 cwts. total draught on an implement which acts on a width of land of from 10 to 12 inches, the utmost total power per inch in width of the soil acted upon will be only 70 lbs. At the same time the resistance will be very much increased by the pressure of the horses' feet in doing the work. For if a horse be taken when the land is in a rather plastic state, and walked across the track of the steam plough and made to travel to and fro transversely on every 10 inches width until a breadth of 6 yards is trodden over, it is then found that, if the steam cultivator has just sufficient steam to perform its work properly before it arrives at the ground so trodden down, it will be completely stopped before it gets through the 6 yards; and considering the momentum of the flywheel, this experiment shows plainly that the power required is something very material, and experience shows one third additional draught to be required on land that has been trodden down to the same extent as in cultivation by horse power. It is clear therefore that a considerable part of the 6 cwts. draught of the horses is expended in undoing the compression caused by their own weight; and as the 4 tons weight of the horses themselves must be lifted up and down all the inequalities of the ground, there is only a very small portion of the animal force left to be usefully exerted upon the implement, and this only at the slow speed at which the horses travel of $1\frac{1}{2}$ miles per hour.

But with steam the case is very different: a draught of 35 cwts. is available upon the implement, giving the farmer the means of

employing a force of from 70 to 280 lbs. per inch in width of the soil moved. And considering that only $1\frac{1}{4}$ tons load is passing over the land instead of 4 tons, much less force is employed to move the same measurement of soil.

The comparison therefore stands thus:—with horses there is a total force of 6 cwts., with the drawback of having to convey 4 tons of useless load over the land; while with steam power there is a total force of 35 cwts. conveying only $1\frac{1}{4}$ tons of useless load. The result of experience is the less weight carried over the land the better; and when the great weight of horses compared with the force they exert is considered, and also the number of footprints left by them on an acre, it cannot but excite surprise that such an unmechanical means of cultivation should have existed so long. The number of footprints left by four horses in ploughing a 12 inch furrow is above 300,000 per acre; whereas the steam plough, which has a width of from 3 to 4 feet, is carried on two wheels 6 inches in width.

The facts that have been stated are surely a good reason why horses should be kept off the ground altogether. If the necessary precautions in this respect are but strictly followed, a complete revolution in agriculture will soon be witnessed, as no mechanical means of pulverising the land will be required, and less than one half the number of operations at present necessary will be found amply sufficient.

Looking at steam cultivation from an agricultural point of view, the question naturally arises why such an improvement should not become general at once. The advantages to the farmer who has met the requirements of steam by appropriate modifications in his farm and in his way of dealing with the land are very considerable: much greater indeed than the most sanguine could have anticipated. These advantages however, from the nature of the case, are but slowly seen, as reliable statistics of the actual results can be obtained only from a series of years. This consideration, together with the want of capital so much felt in agriculture, and the doubts as to the efficiency of steam cultivating machinery which the want of mechanical knowledge induces, leave little room for wonder at

the slow progress of its adoption. The cultivation of the soil is not an investment that yields quick returns; and with the present imperfect appliances it is also a very uncertain investment. Hence the farmer naturally pauses before he invests a larger sum than he has been accustomed to do in such permanent improvements on his farm as will enable him to get the maximum amount of work done in the proper season and at a minimum cost. Such further outlay on the farm must indeed be considered the business of the land owners; but although they will eventually be the principal gainers, few of them have at present given any assistance to the development of steam cultivation. Were they to take the matter up in such a way as an engineer would do, who had seen how he could effect a similar improvement in his mill or factory, the whole country would soon be seen covered with steam ploughs.

The gradual nature of the development of the machinery has also stood in the way of its immediate introduction. For as several persons using the first machine had a great deal of trouble from breakages, others were deterred from following their example, although they witnessed and acknowledged the improvements to the land and crops.

Land, like metal in a furnace, requires the greatest attention in order to perform the different operations at the time when it is in the right state for their being effected thoroughly. The present system of management is entirely inadequate to effect this object, from the want of sufficient force at a given time. In some years there are barely two months for all the cultivation of the season: that is, provided the greatest judgment is exercised, and the land never touched except when in the proper state for the purpose. But with such management as is recommended above, the result will be always an adequate crop.

The advantages of steam cultivation having now been described, and its gradual development during the past few years having been traced together with the various systems employed, it is proposed in conclusion to enumerate what may be considered as the

principal points which are essential to the production of good steam cultivating machinery, so far as regards its mechanical arrangements.

First, a sufficiently powerful engine with a wide bearing surface, and plenty of leverage to move itself out of difficult situations, and of simple construction in all its parts.

Second, a hauling apparatus with a drum of large diameter, and so arranged as to bend the rope as seldom as possible, and with the drum placed horizontally on a vertical axis so as to allow the rope to work in any direction without requiring guide pulleys.

Third, a direct pull upon the implement, with as short a length of rope as possible, and that of good quality, light, hard, tough, and flexible.

Fourth, an arrangement for keeping the rope tight, so as to carry it clear of the ground and avoid loss by friction.

Fifth, an implement in which the shares or tynes follow each other consecutively, wedging off the soil to a loose side.

Lastly, as small an amount of manual labour as practicable.

A few remarks only need be added upon the ultimate effect which will result from the proper adoption of steam cultivation. By thoroughly carrying out the system, definite calculation can be made as regards the cost of working a farm, and better crops will be obtained with a greatly increased amount of certainty. Time, the great point in all business, but more especially in agriculture, will be economised; and from the increased force at the farmer's disposal he will seldom get behindhand with his labour, an evil which at present often causes him to lose a crop altogether in some of his fields. The drainage will be much more efficient, and consequently the temperature of the land will always be kept at the highest point: the result will be that the land will always be in a growing state. Clay land, which is by far the most fit for crops, will be brought to bear the heaviest crops; and this quality of land, which at present pays very little rent, will become the most valuable. Farming will become a business into which a business man may enter with safety, and capital will find in farming a profitable and safe investment, so that increased advantages will accrue to the

country. The intelligence of the agricultural labourer will be improved, in consequence of his having to use his mind more and his body less; and this anticipation has received practical confirmation in not a few cases already.

Mr. GREIG exhibited a working model of the clip drum, and a full size specimen of one of the pairs of clips, together with a sample of the steel wire rope at present used of 11-16ths inch diameter.

He explained that the difficulty of coming to a satisfactory conclusion regarding the relative value of the work done by steam cultivation as compared with horse cultivation arose from the different states of the land upon which the two methods were tried, the different operations to be performed, and the different situations in which the steam cultivators had to be placed. Taking these into consideration, the cost of steam cultivation was found to vary as much as from 2*s*. 6*d*. to 20*s*. per acre; and the expense of working a 14 horse engine, such as was now ordinarily employed for steam cultivation, would not come to more than £3 per day, including interest on the cost of the tackle and implements, allowance for depreciation, and wages; while the engine would work regularly up to the power of thirty ordinary horses. The cost on the other hand of farming with thirty horses, taking it at the very low estimate of only 3*s*. per horse per day and 1*s*. for attendance of men, or 4*s*. total for each horse, would amount to £6 per day, showing a clear saving of £3 per day by steam cultivation, independent of the superiority in the work done by the latter method. The great difficulty of making any calculations as to the cost of farming arose from the difficulty of correctly charging the different items to the different operations. Farmers making the

calculation of the charge of a horse generally fell into the mistake of reckoning it at only 2*s.* 6*d.* per day, forgetting that the horses worked on an average only 150 days in the year and were idle all the rest of the time; and on this account it was frequently difficult to show a farmer the advantages of steam cultivation.

Mr. J. FERNIE remarked that the materials for the valuable paper that had been read had been in preparation by the late Mr. Fowler several months previously, and were left by him at the time when by an unfortunate accident he was so suddenly cut off from the engineering profession and the great agricultural interests which it was the work of his life to benefit. Though removed at the early age of thirty-eight, he had already accomplished a vast amount of work; beginning with the draining plough, he had gradually worked up the system of drainage and cultivation by steam power to the comparative perfection in which he left it, having succeeded in making it a commercial success. In the earlier years Mr. Fowler had been under the necessity of getting his various machines and tackle manufactured in different parts of the country, in order to be able to meet the demand for them; but at his death he left the present large establishment in Leeds, devoted entirely to the manufacture of steam cultivating machinery, employing as many as 700 men, and turning out the machines at the rate of nearly one a day, which were being sent to all parts of the world.

A very important improvement had been effected by the introduction of the clip drum, both in the application of steam power to cultivation and in other cases of communicating power by ropes; and the action of the clips and the great amount of grip which they exerted upon the rope were clearly illustrated in the model now exhibited, having a wire rope passing half round each of two pulleys, one of which was plain, while the other was a clip drum fitted with the clips all round its circumference. On holding the rope stationary by hand, the plain pulley was easily turned round by hand, with the rope slipping round it; but when this was attempted with the clip drum, it was found impossible to turn the drum, on account of the very tight grip with which the clips laid hold of the rope. The clip drum was now applied in other situations

besides hauling agricultural implements, such as for the winding pulleys at the summits of underground inclines in collieries, and in all cases he had observed that the drum was working horizontally; and he enquired whether it was ever employed in a vertical position, working on a horizontal axis, and whether the clips were found to answer equally well in that position.

The steam engines employed for working the various implements used for cultivation and drainage had not been referred to in detail in the paper; and one point deserving of particular notice was the general adoption of a steam jacket surrounding the cylinder, in consequence of which excellent indicator diagrams were obtained from the engines, showing that there was no condensation of steam in the cylinder. Before the use of the steam engine for agricultural purposes could become as extensive as was to be expected from its important advantages over the present sources of power, it was necessary that the restrictions at present imposed upon the use of traction engines on roads should be removed, and that the act of parliament at present in force on this subject should be modified or repealed; and he trusted all the members of the Institution would use their best efforts to attain this object, in the interest both of agricultural progress and mechanical engineering. According to the present act, traction engines were not allowed to pass along the common roads except between ten o'clock at night and six o'clock in the morning; but by taking proper precautions, and having men in front and behind, and shutting off the steam when a restive horse was passing, he was certain that all danger would be done away with. In reference to the condition in which the ground was left after ploughing with the steam plough, he enquired what was the nature of the subsequent further pulverising that had been mentioned in the paper, and whether it was similar to the clod-crushing and harrowing processes that were required after the ordinary ploughing with horses.

They were greatly indebted to Mr. Greig for the excellent manner in which he had completed the paper for the present meeting; and the mechanical details of the system of steam cultivation appeared now to have been so far perfected as to leave

little further to be desired in that respect. He hoped however that they would have the opportunity of hearing the opinions and ideas of those more immediately concerned in agricultural operations, that they might know in what light the system of steam cultivation described in the paper was regarded from a purely agricultural point of view.

Mr. GREIG said that, in reference to the position of the clip drums, there were several of them successfully in use working vertically upon a horizontal axis; and when the clip drum was used vertically, it was best to pay on the rope at the bottom, because there the jaws were sure to be full open from their own weight in addition to the centrifugal force tending to keep them open. With regard to the question of further pulverising the ground after ploughing with the steam plough, he had watched very narrowly the working of the steam ploughs for several years past in connection with some very large farms, and was satisfied that, with proper management and where the steam plough was used in dry weather, there were no such things as clods after the ploughing, and no clod crushers would be required, except in special cases of very light soil, where it might be desired to consolidate the newly ploughed ground by passing the heavy roller or clod crusher over it. Harrows might indeed be desirable after ploughing with the steam plough, but only for the purpose of levelling the surface, as the earth did not require any further breaking up after the ploughing.

Mr. T. B. WRIGHT considered the paper that had been read was a most interesting and valuable one, and he desired to express on behalf of the agricultural community in general the great admiration that was felt for the indomitable energy and unwearied exertions of the late Mr. Fowler in bringing steam cultivation into practical operation. This was one of the most important movements that had ever been originated and carried out in connection with agriculture; and at first the problem appeared so difficult, that it seemed very doubtful whether it would ever be successfully solved. Though it might still be doubted whether the best plan of steam cultivation had yet been hit upon, there could be no question that Mr. Fowler

had accomplished what the Royal Agricultural Society offered their prize for, by showing how it was possible to plough by steam; and the £500 prize offered by the Society for ploughing by steam was accordingly awarded to him at the Chester meeting in 1858. The particular implement indeed was of secondary importance compared with the power by which it was worked; and whether the plough would prove the most useful appliance for steam cultivation, or whether some other implement would ultimately be employed for the purpose, the motive power was the chief consideration; and it was upon this subject that the abilities of Mr. Fowler and his successors had been so advantageously exercised. All farmers would now admit that there could be no worse system than that of using the common plough drawn at a slow speed by several horses, whereby it was not possible to obtain anything like a proper seed bed; but all the disadvantages of the old system were escaped by the use of the steam cultivator. As to any further tillage or pulverising of land that had been ploughed by steam, he thought that generally nothing was necessary but the use of a light harrow, as in the case of the best hand ploughing, for levelling the surface of the ground after the steam plough, in order to leave a good seed bed. With regard to the wire ropes employed for drawing the cultivating implements by steam power, he remembered that the principal difficulty which had had to be encountered in using the iron wire ropes that were in the first instance adopted arose from the great weight of the rope itself and its rapid wear; and it might be mentioned that the first steel wire rope for the purpose had been produced in Birmingham by the late Mr. Webster, which was so superior in strength and lightness to the iron wire rope that when Mr. Fowler saw it he felt satisfied he had met with that which would enable him successfully to carry out his plans of steam cultivation.

The CHAIRMAN enquired what power the engine was indicating at the time of taking the indicator diagrams, and what amount of tractive force that would give upon the implement; and also whether the engines employed were single or double cylinder engines.

Mr. GREIG replied that the indicated power of the engine was about 45 horse power, of which about 75 per cent. would be available at the implement, giving a tractive force of about 30 cwts. total upon the implement. Single cylinder engines were now being made for agricultural purposes, because they were much more simple in all their parts, whilst they were capable of doing the same work as double cylinder engines, and were cheaper in first cost; and he believed that before long the double cylinders would be altogether abandoned for agricultural engines. With double cylinders there was frequently a deficiency of steam in engines of only 12 or 14 horse power nominal, and the friction of the double quantity of mechanism was a serious loss upon the power of such small engines. The only difficulty that arose with a single cylinder engine was in the management of the reversing gear, and at first there was a serious loss of time in starting, whenever the engine happened to have stopped upon the centre. This was now entirely got over however, and there was no longer any trouble in that respect, the only thing necessary being a little judgment on the part of the engine driver, who set the engine going with a small quantity of steam, before starting the implement, so that it was just running slowly; and then by a simultaneous movement of the two handles the clutch was thrown into gear for starting the implement and the full steam admitted to the cylinder at the same instant, when the crank was about at its position of maximum power. In this way all difficulty from the use of a single cylinder was obviated. Mention had been made of steel wire ropes as having been made first in Birmingham, and that was the fact, and the first steel wire rope made there had proved a very valuable one and continued still in use at the present time; but the best steel wire ropes were now however obtained elsewhere, and he hoped the Birmingham manufacturers would take the matter up and recover their original position as makers of the best steel wire ropes.

Mr. E. E. HEWETT enquired what were found to be the results of the system of cultivation described in the paper as compared with the plan of direct traction, in which the engine travelled over the land and drew the cultivating implements after it. He understood that at

the comparative trial of the two methods at Chester in 1858 it had been found that the traction engine travelling over the ground did twice as much work when working up to the same power as the stationary engine pulling the implement by a wire rope from the headland.

Mr. GREIG replied that several attempts had been made to perform steam cultivation by means of a travelling engine drawing the implement after it, but they had in all cases been ultimately abandoned as altogether impracticable. The effect upon the crops was decidedly injurious, as the wheel marks of the traction engine were plainly visible throughout the field in the following harvest, by the crop not being so good and having a burnt appearance in the parts where the wheels had passed and compressed the soil, particularly if the ground had been at all wet at the time of the engine travelling over it. At the same time the consumption of coal to do the same work was at least twice what it would be in a stationary engine working by ropes, as the travelling engine had to convey its own weight over the ground in addition to drawing the implement. In the comparative trial at Chester he believed that, though both engines were nominally of the same power, the traction engine was working at more than double the power of the stationary engine; and although the former was in consequence accomplishing apparently double the work, as estimated by the number and depth of the furrows, yet the work was not performed so efficiently and the ground was not left in such good condition as with the plough drawn by a wire rope from the stationary engine, on the system described in the paper. He was not prepared to maintain that the best method of steam cultivation had yet been arrived at, but there was no question that it had already been brought to a condition of practical efficiency and commercial profit, so as to be worth while to any farmer to take it up; and no doubt there would continually be further improvements in future years, particularly in the implements used, which must be considered to be at present altogether in their infancy. The number of different implements made use of was itself sufficient to suggest that there was ample room for improvement; and he did not see why the three operations

of ploughing sowing and harrowing should not ultimately be carried out at the same time by employing only a single implement for the purpose. One misconception in regard to steam cultivation arose from using the same word to describe the operation of ploughing, whether done by horses or by steam power; whereas the effect produced by steam ploughing was so entirely different as to give it the character of a distinct operation. With the horse plough the soil was simply turned over in a slice, leaving a distinct furrow; but with the steam plough it was either thrown straight up in the air, or thrown sideways to a considerable distance, or broken and turned up from below, according to the shape and arrangement of the shares and mouldboards and the speed at which the implement was driven, and no furrow marks were visible after the process. These different varieties of the operation were severally employed according to the nature of the land to be cultivated, nor did he think that any single process would be applicable successfully to all descriptions of land alike, but the action of the cultivating implement must be varied in every case according to the quality of the land.

Mr. JOHN SMITH remembered seeing the comparative trial at Chester in 1858 that had been referred to, and he thought the traction engine which drew the implement after it had not on that occasion really accomplished so much as an acre of work during the whole time of the trial, and there was a great deal of trouble with it in turning at the ends of the field; also in that case the work done was of inferior character, as the implement only rucked up the soil, without turning it over at all. From the results obtained in the crops produced he was satisfied that the system of steam cultivation described in the paper had everything to recommend it. A farmer whom he knew in the neighbourhood of Wolverhampton had adopted a set of Mr. Fowler's tackle and implements several years ago, which had proved completely successful, notwithstanding that it was one of the earlier arrangements involving the trouble and inconvenience of the three drums under the engine and a number of guide pulleys for the rope to pass round in the field. One of the fields so ploughed about five years ago, which had previously been very deficient in its crops,

had never failed to yield a good crop since, and appeared likely to continue equally productive for years to come. It was a field that threw up a great deal of coltsfoot and dock, and had therefore been ploughed as much as 12 inches deep, since which there had never been any trouble at all with those weeds.

The CHAIRMAN enquired whether steam cultivation was resorted to in foreign countries for any other purposes than those known in England.

Mr. GREIG replied that a considerable number of the steam ploughs had been sent out to sugar plantations, and most favourable accounts had been received of their working. It was found that a sugar plantation of about a hundred acres would pay for a steam plough with engine and tackle complete by the difference in the crop of sugar produced in a single year; and this was a most satisfactory and decisive result in favour of the steam plough. In Cuba, owing to the very dry season last year, there had been scarcely any sugar crop at all except where the steam plough had been used; and the explanation of the difference he believed to be that by means of steam power the land was ploughed before the dry weather set in, and consequently retained sufficient moisture during the whole season. There were also a considerable number of the steam ploughs in Egypt, some on sugar plantations, but the greater part employed in the cultivation of cotton; the great stimulus given to the growth of cotton and the dearth of animal labour had necessitated the employment of steam power in Egypt. Steam ploughing was also being done on the land recovered by the drainage of Haarlem lake; and in that case, owing to the very soft nature of the soil, the wheels were made 2 ft. 6 ins. broad, in the manner shown in the drawing, for obtaining sufficient width of bearing surface on the ground.

The CHAIRMAN enquired whether the steam draining plough was still in use, as described by Mr. Fowler in his former paper in 1857, and whether any material alterations had been made in the operation.

Mr. GREIG replied that the draining ploughs had been used considerably in Essex, and there were at present ten of them in different parts of that county, which were constantly in use,

answering both practically and commercially, and earning a considerable sum, as they were let out extensively for hire to the farmers in the district. The use of drain pipes was now abandoned in clay land, as it was found that the simple hole bored by the draining plough was all that was required; the only difficulty was where the soil happened to change in character along the course of the drain, because in a sandy soil the drain might drop in; but in clay land there was no difficulty whatever from that cause. The drains were bored at about 3 feet depth and about 16 feet apart; the holes might be bored any size, but generally it was found best to make them about 4 or 5 inches diameter. At one time about 150 acres of land at Hainault had to be drained with drains 4 feet deep by means of the steam draining plough; but it was afterwards found that that depth was too great, as the water could not penetrate into the drains owing to the great compression of the clay at such a depth. Down to about 3 feet or $3\frac{1}{2}$ feet depth however the drains were found to answer very well in the clay land.

Mr. E. T. BELLHOUSE enquired, in reference to the use of a single-cylinder steam engine for ploughing, whether such an engine was suitable also as a traction engine; because he did not think any system of steam cultivation would be complete, unless the engine were capable of transporting itself from one place to another together with the implements and tackle. An engine was therefore required that would both work the plough and serve as a traction engine; and there were so many difficulties in getting over the ground where the roads were bad that nothing but an engine of the strongest character would be able to do the work it would meet with.

Mr. GREIG considered a single cylinder engine was the best for a traction engine, and he had found no difficulty in the working of such engines. That was evidently the opinion also of one of the principal makers of traction engines, who made none but single cylinder engines for the purpose. As to the ploughing engine being used for a traction engine, it had as a ploughing engine to overcome difficulties that a traction engine seldom encountered, and therefore any engine that was a good ploughing engine must be

strong enough to be a good traction engine also. Their present practice in the construction of the single cylinder engines was to place three quarters of the weight upon the driving wheels to be available for traction, leaving only one quarter on the front wheels to steer by. At first it had been feared to put the machines to work upon stony lands, lest large stones should damage the implements and put too great a strain upon the engine. This fear proved however to be without foundation, and in one case that he had witnessed a machine put to work on very stony land was tearing up stones as large as 4 feet long by 2 feet wide and 1 foot thick, and tearing up no less than 20 tons of stone per acre: the machine did 70 acres of that sort of work, and came back with only two tynes bent in the cultivator. Such results far surpassed all previous expectations as to the capabilities of steam cultivating machinery.

The CHAIRMAN enquired whether both the driving wheels of the engines were driven by the power, and how the steering was managed with the very broad wheels that had been alluded to.

Mr. GREIG explained that each driving wheel was driven by a friction clutch keyed upon the driving axle, and the friction clutch on one side was screwed up tight, while that on the other side was only half tight, so as to allow of slipping in turning; or in a sharp turn one friction clutch was slackened altogether, allowing the wheel on that side to run loose on the axle. By this means the engine was turned readily, whatever might be the width of its driving wheels.

The CHAIRMAN enquired what was generally the expense of steam cultivation, and the absolute cost of the machinery and the repairs.

Mr. GREIG replied that a 14 horse power engine with implements and tackle complete might be reckoned at less than £1000, the actual cost being about £944. There were two implements supplied with each engine, of different construction, a cultivator with seven shares and a plough with four; the cultivator was for going over the land previously ploughed, and its shares or tynes had only a cutting action without turning the soil over. The total cost of repairs, to allow for renewal of the whole, might be taken safely at 15 per

cent. on the outlay, being 10 per cent. for the working repairs and 5 per cent. interest. For working the engine and implements two men and three boys were required, making the cost for labour about 10*s*. per day. In case of having two engines, one at each end of the field, three men and two boys would be employed, and the two engines of 7 horse power in place of one of 14 horse power would raise the total cost to about £1140.

The CHAIRMAN enquired whether accidents to the machinery were of frequent occurrence or whether the expense of repairs arose from the mere wear and tear of the engines and machinery. It appeared that very little trouble was experienced from the large stones sometimes met with, and he enquired whether the repairs of the rope formed any considerable item in the expense.

Mr. GREIG replied that the repairs were merely those arising from regular wear and tear, and accidents of any sort seldom occurred. The steel wire ropes were now made so strong that they seldom broke on less than 1000 acres, and 2000 acres were now often done before any breakage took place. There was indeed no fear of breaking the rope; for if the implement caught against a stone the rope would stop the engine dead before it would break; and the cost of maintenance of the rope was the merely nominal sum of only about 6*d*. per acre.

Mr. E. E. HEWETT enquired whether the steam plough was able to plough the whole of the field, or whether a second plough had to be used to finish the headlands afterwards, and what percentage was generally left unploughed.

Mr. GREIG explained that each field was completed by the steam plough itself, the headlands being left unploughed; and on that account it was not profitable to take the steam plough into small fields, say only 7 acres: such small fields indeed should not exist at all for steam cultivation, and it was found that the steam ploughs were never purchased for farms that were cut up into small fields. In large fields of 20 or 30 acres the land left unploughed would probably not be more than half an acre, unless there were very crooked fences which would prevent the engine and implements from being worked in favourable positions. If it were desired in

any field to plough the headlands also, it would be better to plough them by horses, in order to save the time and labour of readjusting the engine and tackle for such an insignificant amount of work.

Mr. W. RICHARDSON asked whether the engines would work best far asunder or close together, supposing the steam plough were working in an unenclosed country like Egypt or South America where the ground could be laid out in any way that was found best.

Mr. GREIG considered the most profitable mode of working was to have the two headlands about 300 or 400 yards apart. Sometimes fields had been met with where the headlands were 500 yards apart, but that distance took all the strength of the rope to do it. When the distance apart was increased beyond the ordinary run, the increased wear and tear of the rope more than counterbalanced the time saved in turning; so that in the case of a width of 600 yards it would be better to plough it in two widths of 300 yards each, because there would be less wear and tear. On the other hand in small fields there would be a considerable time lost in turning at each headland.

The CHAIRMAN remarked that the paper had shown clearly the successive stages by which the present system of steam cultivation had been arrived at; and he had himself had an opportunity of seeing the steam plough at work two or three years ago, both on the second plan described in the paper, with the stationary engine in the middle of one headland and the rope led round anchor pulleys at the opposite sides of the field, and also on the improved system of direct pull, getting rid of many of the bends in the rope, which was now carried out with so much success. It was clear now, from the experience previously gained, that there had been two very important objects to be attained: the one to get rid of as much weight in the rope as possible, by making the rope itself as small as possible; and the other to make the bends in the rope easy and few in number, and reduce the wear and tear on the rope in driving. The former of these objects had been accomplished by the use of steel instead of iron wire in the manufacture of the rope; and the latter by the clip drum, which was certainly a most ingenious and valuable contrivance, and had been found to work

with the greatest success and regularity. He had seen the clip drum in use in the horizontal position shown in the drawings, in which it was employed in steam cultivation, and had been much struck by the boldness of the method of adjusting the distance between the upper and lower row of clips, so as to adjust the whole set simultaneously by a single turn, by the simple expedient of chasing a screw thread upon a drum of even 7 feet diameter, instead of employing a separate adjustment for each pair of clips, which might at first sight have seemed the only way to effect the object; and the screw was found to answer the purpose in the most thoroughly satisfactory manner. The contrivances for taking up the slack of the rope so as to keep it clear off the ground were also particularly deserving of notice, from their simplicity and practical efficiency in accomplishing what was evidently a point of much importance to the success of the system. The slack gear on the plough itself ensured the rope being drawn tight by an entirely self-acting apparatus before the plough started in either direction, and the action was reversed simply by the ploughman taking his seat at one end of the implement or the other. The compensating break attached to the winding drum also served to prevent the rope becoming slack, the rope being drawn off under the constant tension kept upon it by the friction of the break.

He had no doubt that the time was coming when the use of engines upon common roads would be a necessity, and that horses would soon become accustomed to the passage of a steam engine; and if at first they were frightened it was very easy to stop the engine. But the use of engines on common roads ought not to be prohibited merely on account of frightening horses, any more than soldiers were prevented from marching through the streets because horses would take fright at the sound of the drum. He remembered travelling frequently by Hancock's steam carriage, which used to run regularly twenty-five years ago through the streets of London from the Bank to Paddington, at a speed of 7 or 8 miles an hour or even 10 to 12 miles an hour on good parts of the road. At first the horses were certainly much frightened at it, but when it had been running a month the omnibus horses took no notice of it at all.

He was sure all the members must feel greatly indebted for the full and able paper that had been read; and while they deeply regretted the early loss of so eminently practical and energetic a member of the engineering profession as the late Mr. Fowler, there was no reason to doubt that the work he had so admirably begun would be ably carried on by his successors.

He proposed a vote of thanks to Mr. Greig for the paper, which was passed.

The following paper, communicated through Mr. Walter May of Birmingham, was then read:—

DESCRIPTION OF A HIGH-SPEED COMPRESSED-AIR HAMMER, FOR PLANISHING, STAMPING, FORGING, &c.

By Mr. WILLIAM D. GRIMSHAW, of Birmingham.

The objects of this Compressed Air Hammer are to obtain a self-acting hammer with a great range in the force and rapidity of the blows, so as to be suitable for light forging, tilting, and planishing; or capable of being worked by hand with heavy blows for stamping when required; and also arranged to be driven by a belt from a shaft, in order to be applicable where direct steam power is not available. The machine consists of a force pump supplying compressed air to a reservoir, and a working cylinder and piston with hammer similar to those of a steam hammer, but worked with compressed air instead of steam, and having arrangements for varying the action of the hammer as required, and increasing the rapidity of the blows considerably beyond the speed of revolution of the driving pulley.

The hammer is shown in Figs. 1 to 6, Plates 14, 15, and 16. Fig. 1 is a side elevation of the hammer, partly in section; Figs. 2 and 3 are front and back elevations; and Fig. 4 is a plan, partly in section.

The double-acting air pump A, Fig. 1, is 8 inches diameter and 8 inches stroke, and is worked by a crank pin on the driving pulley B; it has a solid piston fitted with cupped leathers, and cast iron suction and delivery valves C, which are circular with flat faces, and each fitted with a light spring on the top to close the valve promptly. The interior of the hammer frame D forms the reservoir, into which the compressed air is delivered by the pump, and the pressure is regulated by the safety valve E, with a sliding weight or spring balance to alter the working pressure of the

hammer. The piston F of the hammer cylinder is 4½ inches diameter, packed with cupped leathers, and has a full stroke of 10 inches. The compressed air is admitted below and above the piston alternately by the slide valve G at the top of the cylinder, and escapes by an exhaust port at the side of the cylinder H. The pressure of the air admitted to the cylinder from the reservoir D is regulated by the throttle valve I, worked by the foot treadle K; the throttle valve spindle is seen in Fig. 5, which is a horizontal section through the hammer cylinder.

The slide valve G is of cast iron, and is shown separately to a larger scale in different positions in Figs. 7 to 11. It is faced both back and front, with the ports passing through to the back; and two adjustable cut-off slides J J are placed on the back for altering the points of cutting off the air. These are regulated separately by screws L L, which pass through the side of the valve-box, and serve to hold the cut-off slides stationary in any desired positions.

The slide valve G is worked by a crank pin on the horizontal disc M, Figs. 1, 4, and 6, and this is driven by contact with the vertical wheel N upon the shaft of the driving pulley B; the disc M is pressed down by a spiral spring O upon the lower end of its spindle, as shown in the section Fig. 6, and the vertical wheel N is faced with leather on the edge, to give the required adhesion for driving it. This wheel N slides along the driving shaft upon a feather, and is shifted by the lever P, varying the speed of driving the disc M by acting upon it at different distances from its centre, and thereby giving a range of speed for driving the slide valve up to more than double the rate of revolution of the main driving pulley B. By means of the lever P, which is held in a series of notches, the number of blows of the hammer can thus be changed, without stopping it, from 150 up to 420 per minute, with the usual working speed of from 150 to 200 revolutions per minute of the driving pulley.

The valve spindle is connected with the crank pin on the driving disc M by a connecting rod R having a forked end, as shown in the plan, Fig. 4; and this can be at once disconnected by withdrawing the fork R by means of the handle S. The slide valve is then

worked by hand or foot by means of the lever T, when the hammer is required to be used for stamping; and the lever T is removed by drawing it out of its socket when the hammer is required to be worked self-acting.

An efficient hammer worked by compressed air is found very advantageous in many situations, such as where there would be material loss of power by condensation in bringing steam from a great distance, or where the damp from leakage of steam or the dropping of condensed water on the anvil would be objectionable, as in shops where bright steel is exposed or where the planishing of bright work is carried on. The air hammer also meets the cases where horse power or other power than steam is alone available; and it has an advantage in being always ready for work, not having any accumulation of condensed water in the cylinder and passages as in the steam hammer. There is also a saving in lubrication and in wear of the working parts, from their not being exposed to the heat of high pressure steam.

In this air hammer the force, rapidity, and quality of the blow can be changed with great promptness and accuracy. The force of the blow is regulated by shifting the safety valve weight E, or by means of the throttle valve I altering the pressure of air upon the top of the hammer piston; and the slide-valve motion admits of altering the rapidity of the blow instantaneously, giving also the means of obtaining a very high speed without involving any destructive tappet action, as the small slide valve G is alone required to be worked at the high speed. The arrangement of the cut-off slides J gives the means of regulating the quality of the blow, from a full stamping blow, to a sharp pick-up blow striking with any degree of lightness and well suited for such work as planishing and shaping hollow ware; and by the use of the hand or foot lever T the hammer is readily and conveniently worked as a simple stamp.

A working model of the hammer was exhibited, and shown in action.

The CHAIRMAN enquired where any of the hammers were in use, and what work they were employed upon.

Mr. GRIMSHAW replied that several of the hammers were now in use in Birmingham and the neighbourhood, employed for various stamping and forging purposes; also one at Glasgow for coppersmith's work, shaping and planishing vacuum pans for sugar refining, and one at Sheffield for steel tilting. The pressure of the air could be varied by altering the load on the safety valve, and the hammers had been worked at pressures from 7 to 30 lbs. per square inch; the ordinary pressure at which they were worked was about 20 lbs. per square inch.

Mr. E. T. BELLHOUSE enquired whether the hammer had been used for forging iron, as in a smith's shop; and whether in stamping plate iron it had been tried stamping the metal cold.

Mr. GRIMSHAW replied that one of the hammers had been at work for more than seven months in a smith's shop for ordinary forging work; and in that case it was employed also for blowing the fire in the intervals while the iron was being heated, by a connecting pipe being carried to the tuyere from the air reservoir. In stamping plate iron the hammer could be used for stamping the metal either hot or cold as might be desired.

The CHAIRMAN asked what was the greatest number of blows per minute that had been obtained with the hammer.

Mr. GRIMSHAW replied that the greatest speed at which the hammer had been worked was 800 strokes per minute, and it could be driven at any number of blows below that amount. It was usually worked self-acting for any speed above 100 blows per minute, but below this it was generally preferred to throw the self-acting motion out of gear and work it by hand; or in case the workman wanted both his hands free, the treadle gave the means of working the hammer by foot.

Mr. W. RICHARDSON enquired what was the size and cost of the largest hammer that had been put to work yet, and what pressure of air it was worked at.

Mr. GRIMSHAW replied that the largest of the hammers yet put to work had a cylinder 8½ inches diameter and a stroke of 28 inches; he did not know what pressure it was working at, but the pressure might be adjusted to any amount from 5 lbs. up to 40 lbs. per square inch. The cost of such a hammer was about £180, and of a hammer of the size shown in the drawings about £50, the larger hammer requiring about 5 horse power to drive it, and the smaller about 1 horse power.

Mr. E. H. CARBUTT thought the air hammer was not as suitable for steel tilting, and would not be able to compete with the steam hammer for that purpose, since its power was not to be compared with that of the steam hammer. The greatest advantage of the air hammer he considered would be for stamping small articles, in place of hand labour.

The CHAIRMAN enquired what was the greatest speed of blows that was obtained by the steam hammer.

Mr. E. H. CARBUTT said that several steam hammers of from 4 cwts. to 10 cwts. were working in Sheffield, with which 500 to 600 blows per minute could be struck if required; and they were regularly working at 300 blows.

Mr. GRIMSHAW observed that in reference to tilting steel there was one of the air hammers now at work in Birmingham which was employed in drawing down steel; a bar of steel 4 inches long and ⅝ inch square was drawn down to a length of 14 or 15 inches with a regular taper, and 36 of these were produced by the hammer in 19 minutes in the ordinary work, which he believed it would be impossible to accomplish by any steam hammer at present employed. The average speed of the air hammer for that work was about 340 blows per minute in regular working, and that was as fast as the man could turn his hand for turning over the mould between each blow; the speed could however be increased whenever desired up to 600 or even 800 blows per minute. When the drawing of the steel was finished, the hammer could be stopped instantly, with a promptness which could not be attained with the steam hammer.

Mr. W. RICHARDSON thought all that had been performed by the air hammer in steel drawing and other work could be accomplished equally well by ordinary steam hammers, as regarded both the rapidity and force of the blows. The main advantage he considered to be gained by the use of the air hammer would be preserving the die always dry and free from liability to droppings of condensed steam; there were many kinds of work in which a dry die was a matter of great importance, and for such cases the air hammer appeared admirably adapted; but for general work he did not think it could compete with the steam hammer.

Mr. GRIMSHAW mentioned that the steam hammer had been abandoned for steel tilting at some of the works in Sheffield, and the air hammer adopted instead, as it was found preferable for the purpose. At Messrs. Sanderson's works one of the air hammers had been at work for a considerable time for bolstering and forging knife blades &c.; and at another steel works a shop was going to be built to contain six of the air hammers.

Mr. C. H. ADAMES said that he used to employ steam hammers for planishing hollow ware at his works in Birmingham, but had been obliged to abandon them for bright iron work, on account of the droppings and moisture from the steam; and he had now put up for the purpose one of the air hammers described in the paper, which had been at work for ten months and had proved very successful and had shown he considered a decided economy as compared with steam. He accordingly intended to remove two steam stamps of large size at present in use, and replace them by air hammers, which he was satisfied would answer well.

The CHAIRMAN remembered an air hammer being made by the late Mr. John Hague about thirty-five years ago, which he believed was one of the earliest air hammers that had been made. It was worked as a vacuum hammer, by exhausting the air, instead of by compressed air, and was constructed for the purpose of planishing frying pans; and it worked with such an extraordinary rapidity that it was impossible to see where the hammer was in working, and the effect seemed more like giving one continuous pressure. That hammer was however wanting in the elegant contrivance for

regulating the blows that was shown in the hammer now described; and he was particularly pleased with the mode of working the slide valve by the neat arrangement of the friction wheel and disc running in contact with each other. He enquired how the surfaces of the wheel and disc had been found to stand in work, and whether there was much liability of their slipping; and what amount of repairs had been required to any of the hammers.

Mr. GRIMSHAW replied that in the first of these hammers that was put to work the surfaces of the friction wheel and disc for working the slide valve were merely iron against iron, and worked in that condition for seven months with only an occasional slipping when a little oil from the bearings happened to get upon the surface of the disc. Afterwards the bearing of the disc had been recessed, and formed into an inverted cup, to prevent any risk of oil getting upon the rolling surface; and the friction wheel had been faced with leather to increase its hold upon the disc and diminish the wear. No repairs had yet been required to any of the hammers at present at work, and the only accident that had occurred to any of them had been that the cylinder bottom got broken through an accident in the first hammer, which had been put up mainly with a view to testing the cost of working and the actual wear and tear of the several parts.

The CHAIRMAN moved a vote of thanks to Mr. Grimshaw for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

1 AND 2 AUGUST, 1865.

The ANNUAL MEETING of the Members was held in the Examination Hall, Trinity College, Dublin, on Tuesday, 1st August, 1865; ROBERT NAPIER, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

JOHN J. BAGSHAWE,	Sheffield.
CHARLES BELL,	Stoke-upon-Trent.
CHARLES BLADEN,	Jarrow.
GEORGE BROWN,	Rotherham.
FREDERICK WILLIAM BRYANT,	London.
SAMUEL CARLTON,	Swindon.
JOHN CLARKE,	Leeds.
VICTOR COATES,	Belfast.
JAMES CROSS,	St. Helen's.
JAMES DAVIDSON,	Woolwich.
CHARLES KELLOCH DOMVILLE,	Belfast.
CHARLES P. DOUGLAS,	Gateshead.
FRANK EVERS,	Stourbridge.
SAMUEL CLOUGH FAVIELL,	Leeds.
EDWARD FILLITER,	Leeds.
GÖRAN FREDRICK GÖRANSSON,	Gefle, Sweden.

William Arthur Harrison,	Manchester.
John Heptinstall,	Rotherham.
John Muir Hetherington,	Manchester.
John Holliday,	Westbromwich.
Edward George Jarvis,	Gloucester.
William MacNay,	Darlington.
Daniel Macnee,	Sheffield.
Alexander McDonnell,	Dublin.
John Robinson,	Rochdale.
Alexander Thorn,	London.
George Moon Usher,	Beverley.
Andrew Wyllie,	Liverpool.

HONORARY MEMBERS.

Alfred Longsdon,	London.
Thomas Warden,	Birmingham.

The following paper was then read :—

ON MACHINERY EMPLOYED IN THE PREPARATION AND SPINNING OF FLAX.

By Mr. THOMAS GREENWOOD, of Leeds.

The manufacture of Flax is from a variety of causes one of the most interesting of textile manufactures; and although not one of the most extensive is of considerable importance, the exports of linen and linen yarn from this country amounting to upwards of £8,000,000 for the last year. As a manufacture it is one of the most ancient, the fine linen cloth of Egypt having been employed in a very remote period for embalming; and examination by the microscope confirms the fact that this cloth was made of flax and some of it of a fine quality. Yet there is not the slightest evidence that this linen was spun otherwise than by hand by means of the distaff, the method of spinning in those days being the same that prevailed in this country up to a very recent period, and is still extensively practised in the north of Europe in the neighbourhood of Archangel and the White Sea.

The processes of cultivating and retting flax seem to have been similar in all countries where it was grown, and steeping or dew-retting was the prevailing method in its preparation. Some years ago artificial methods were introduced to supersede this natural process of retting; but their success has only been partial, and in the chief flax producing countries the natural system prevails. The stalks of flax are pulled up by the roots and set up in bundles to dry, and the seed is then stripped off. The "retting" consists in steeping the stalks in partially stagnant water for about three weeks, during which time a fermentation takes place. The flax fibre being

the bark or rind of the flax plant, of which the interior or core is a semi-wooden substance called "boom," the object of retting is partially to decompose this woody substance, so that it becomes brittle when dry; and the fermentation should not be continued so long as to injure the strength of the fibre, but long enough to loosen the gum which causes the bark to adhere to the woody portion. The process therefore requires great care and experience, for either too much or too little retting is detrimental to the fibre. When thoroughly dried, the flax is ready to be broken, which is done by passing it in small bunches through pairs of fluted rollers; these break the woody core into short lengths, and also partially split the bark.

The next operation is called "scutching," which in most flax producing countries is still done by hand in preference to mill-scutching. In hand-scutching, a bundle of the broken flax is suspended alternately at each end and struck with a wooden beater, by which the broken pieces of the core or boom are dusted out from between the fibres. This operation requires considerable dexterity, for some of the finest flax is worth £200 per ton of fibre, so that any waste or damage to the fibre by getting it entangled is a serious loss. The bark or fibre at this stage ought to appear like narrow strips of tape; unbroken and unentangled, or the yield will suffer in the next process of "heckling." In Ireland last year the flax crop covered upwards of 300,000 acres, producing 80,000 tons of flax at an average value of £60 to £70 per ton; and the hand-scutched flax realised about 20 per cent. higher price than the mill-scutched.

The next process is to "heckle" the flax, which was formerly done by hand by the flax dressers. The heckle is a board set closely with pins about 4 inches long, which are ground to a fine tapering point; this board is fixed with the points of the pins upwards, and the bundles of flax are drawn over the pins until the flax is sufficiently split. Other heckles of varying degrees of fineness are also used, partly to bring up the fibres to the requisite degree of fineness, but chiefly to clear out the short loose fibres or tow which were split off in the first heckling. The dressed flax was sold in

this state under the name of lint, for spinning by hand, which was formerly a common domestic occupation both of rich and poor.

In the early application of machinery to preparing and spinning flax, the fibres were drawn between two pairs of rollers, the first called the receiving rollers and the other pair the drawing rollers, the two pairs of rollers being placed at varying distances apart, according to the length of fibre to be operated upon. The drawing rollers ran at from 5 to 10 times the surface speed of the receiving rollers, so as to elongate the "sliver" or bundle of fibres. Subsequently a series of "travelling gills" was introduced between the receiving and drawing rollers, these being a succession of small transverse combs, called gills, travelling continuously forwards in the longitudinal direction of the fibres about 5 per cent. faster than the surface speed of the receiving rollers. This proved a step in the right direction, and was followed by the introduction of spinning frames similar to those employed in spinning cotton, but with the modifications rendered necessary by the difference in the material to be spun: the chief feature in the flax machinery being the great difference in the distance between the receiving and the drawing rollers, which amounts to as much as 20 to 24 inches distance in the case of flax, instead of at most only a few inches in the case of drawing cotton, on account of the great difference between the length of fibre in the two materials.

The flax was at first kept quite dry in the spinning process; but a mode of damping the yarn by means of a piece of wet cloth held in contact with the drawing roller was afterwards employed, which had the effect of laying the loose ends of the fibres in the same manner as is done by wetting the fingers in hand-spinning. But the great expansion that has taken place in the flax trade is due to the principle of wet spinning introduced by the late Mr. Kay: the flax rovings being first put into warm water and allowed to stand until fermentation took place, by which the flax was macerated and brought into a state bordering on putrefaction. This was found however to be a dangerous process, for if continued too long the strength of the fibre was destroyed. Subsequent

experience showed that it was only necessary to pass the rovings through hot water in order to attain a better result, and that no maceration was requisite. It is only the natural gum contained in the flax fibres that requires to be dissolved or softened, in order to allow them to be drawn asunder; and the slimy nature of the rovings when wet allows this to be done to almost any extent. When spun dry by machinery, No. 40 yarn was about the maximum degree of fineness attained, in which the "bundle" of 60,000 yards length weighs 5 lbs.,* and this size of yarn is suitable for ordinary linen cloth; but now by the improved process of wet spinning Nos. 300 to 400 are ordinarily attained, in which sizes of yarn the "bundle" of 60,000 yards length weighs only $\frac{1}{5}$ and $\frac{1}{4}$ lb. respectively. The whole of this advantage indeed is not due to the principle of wetting the roving, but many improvements in the preparation have contributed to the attainment of this result. One of the conditions of spinning flax wet is to bring the receiving and drawing rollers within a few inches of each other, and thus reduce the length operated upon of the fibre of the flax to the distance between the bite of the receiving and drawing rollers. Yet notwithstanding all the improvements of machinery, hand-spinning still produces a yarn of three times the fineness hitherto attained by the finest machine; for while Nos. 300 to 400 are the finest produced by the machines, the hand-spinner produces yarn from Nos. 1000 to 1200, in which the "bundle" of 60,000 yards length weighs only 1-5th and 1-6th lb. respectively. This finest kind of yarn, the value of which is equal to that of gold, weight for weight, is produced

* The "bundle" of flax yarn consists of 200 leas or hanks of 300 yards each, making altogether 60,000 yards length; and the Nos. are marks indicating the sizes of the yarn in inverse proportion to the weight of the "bundle," as in the following table, the unit being No. 200 weighing 1 lb.:—

No. 10 yarn weighs	20 lbs.	per bundle	
No. 20	10 lbs.	,,	
No. 40	5 lbs.	,,	
No. 50	4 lbs.	,,	
No. 100	2 lbs.	,,	
No. 200	1 lb.	,,	
No. 200 yarn weighs	1 lb.	per bundle	
No. 300	2-3rds lb.	,,	
No. 400	2-4ths or $\frac{1}{2}$ lb.	,,	
No. 500	2-5ths lb.	,,	
No. 1000	2-10ths or $\frac{1}{5}$ lb.	,,	
No. 1200	2-12ths or $\frac{1}{6}$ lb.	,,	

chiefly in Belgium, and is used for making Brussels lace. The subsequent manufacture of flax after the yarn is produced presents great variety, the fabrics made from it ranging from the roughest "Dudley cambric" used for nail bags to the finest lawn, and from the stoutest ship's sail to the lightest gossamer lace.

Since the introduction of the principle of spinning flax wet, various methods have been adopted to render the fibre of the flax finer, or in other words to split it up into a greater number of fibres by the process of heckling. The quality of the flax varies very considerably, as indicated by the price, which ranges from £35 to as much as £200 per ton of fibre. In order to obtain the finest fibre it was found necessary to break or cut the flax into three lengths: the top of the plant, the middle, and the root end. Of these the middle is the best part, owing to the fibres being there most uniform in thickness. By this plan of dividing the natural length of the flax into three lengths, which is designated the "cut-line" system, a very much smaller proportion of short fibres is produced in the heckling process than by heckling the fibre the full length of the plant; and consequently the fibres can be split much finer, and a larger proportion of yarn can be produced from a given quantity of flax, the degree of fineness being taken into account. Another system is to cut the length of fibre in half; but this although partially pursued is wrong in principle, as the flax is then cut in the middle or most valuable part of the fibre, and each length has one bad end, the tapering end of the top of the plant, and the coarse end of the root. A third system is to heckle the flax the whole length of the fibre, which is called the "long-line" system, and is the most economical for the ordinary numbers of yarn that always constitute the great bulk of the manufacture. On this system a greater weight of flax can be passed through the heckling and preparing machinery in a given time; and a longer "draft" can be used at the spinning frame, that is the excess of surface speed of the drawing rollers above that of the receiving rollers can be made much greater than in the three-cut and two-cut systems, thereby producing a greater drawing action and making a finer thread, whilst reducing also the labour in attending to the process.

The machinery used in the three-cut and two-cut systems is the same as in the long-line process, only that in the former it is finer in the gills and rollers and shorter in the reach or distance between the pairs of rollers. For some descriptions of manufacture it is absolutely necessary to use the long-line process, as for instance in making the best kind of sail cloth, which is used in the royal navy and in the finest long-voyage vessels. For this purpose the longest and strongest flax is selected, and prepared with the greatest care in the processes of heckling, drawing, and roving, so as to preserve the fibres as long as possible; and in the spinning, which is done dry, very short drafts are used, that is the excess of surface speed of the drawing rollers above that of the receiving rollers is comparatively small, so as not to break the fibre any more than can be avoided. The government authorities insist upon a test of both weight and strength at the same time, in order to get the sails both strong enough to resist the wind and also as light as possible for the sailors to handle; for as the weight of the mainsail of a first-class ship amounts to more than a ton, it is no easy task to handle it in a gale of wind and rain.

The machinery at present in use for preparing the flax and spinning it into yarn for weaving &c. is shown in Plates 17 to 29.

Fig. 1, Plate 17, represents the Breaking Rollers, which are fluted iron rollers coupled together by spur wheels; and both top and bottom rollers are supported in journals, so as to prevent the flutes from touching each other. The spaces between the teeth of the flutes are also much wider than the teeth working into them, so that as the rollers revolve the flutes never come in contact; otherwise the iron would damage the fibre. The object of passing the flax between these rollers is simply to break the boom or woody interior of the flax.

After the flax has been broken between the rollers, it is taken to the Scutching Machine, shown in Figs. 2 and 3, Plate 17. The scutching cylinder A rotates in the direction of the arrow at about 300 revolutions per minute or 2,800 feet per minute speed of circumference, and dashes out the broken boom against the

grating D by means of the toothed and plain projections B and C. The drawing shows one pair of combs B and five pairs of plain square beaters CCC upon the cylinder A, which are found to act well; but the number of either may be altered. The strick of broken flax is fed into the machine by the attendant up to half its length; and when the boom is thoroughly beaten out, it is drawn back and the other half inserted in the same way. The broken boom beaten out through the grating D escapes by an opening at each end of the grating. The ends of the casing of the machine being closed, a considerable current of air is drawn in through the grating D by the rapid rotation of the scutching cylinder, which is an essential feature in this operation, in carrying away the refuse and dust, and producing a gentle pressure of the flax against the projecting beaters upon the cylinder. The bottom of the casing of the scutching machine is open, and communicates with a flue or culvert, through which the refuse and dust are carried away by the current of air.

The next process is to heckle the flax, and Fig. 4, Plate 18, shows an end elevation of the Heckling Machine. The flax is divided into small stricks, and each is held between a pair of clamps A called holders, made sometimes of hard wood but latterly of steel. These are closed firmly together by a bolt, as seen in Fig. 5, Plate 19, and are lined with either felt or india-rubber to form a cushion for the fibre to bed upon. The heckling machines vary in length, having sometimes four, six, or eight holders in a row; and the heckles BB have corresponding degrees of fineness, according to the amount of heckling that the flax will bear, the stricks of flax being submitted first to the action of the coarsest heckles, and then to the finer heckles in succession. The holders A are carried in a trough C, which extends the entire length of the machine, and also projects some distance at each end, so as to afford room for feeding in at one end the newly charged holders and removing from the other end those containing the heckled flax. The trough C receives a vertical motion from two cams D, shown by the dotted lines, mounted on the shaft E below, the weight of the trough being balanced by the

weighted lever F. The form of the cams D is so arranged as to bring the pendent end of the flax gradually under the operation of the heckles, and also to allow a slight pause when the trough has descended to its lowest point, as shown in Figs. 4 and 5, so that the heckles may comb out the fibres straight, and effectually clear out the tow. The trough C then rises again gradually; and when it has reached its highest position, as shown dotted in Fig. 4, the row of holders A are pushed forwards along it, by a series of pauls mounted upon a bar extending the entire length of the trough and acted upon by the lever G and cam H. Each strick of flax is thus carried along to the next gradation of heckles, and the trough C then again descends as before. The set screw I, Fig. 4, is for the purpose of adjusting the height of the trough A, so as to allow the holders to come down as near as possible to the bite of the heckles.

Fig. 5, Plate 19, represents an enlarged transverse section through the middle of the heckling machine. The sheets of heckles BB are made of leather straps passing round the small pulleys JJ at top, and round the larger driving pulleys KK below, travelling at the rate of about 800 feet per minute in the direction indicated by the arrows. The heckle bars LL are of wood, attached by only one edge to the straps B, so that when they have passed over the top pulleys JJ the heckle pins may strike into the pendent flax as nearly at right angles as possible, as seen at the top of Fig. 5. The heckles then descend in a vertical line until they reach the lower pulleys KK. These pulleys are grooved radially, and small slides carrying small iron rods MM are thrown out by the centrifugal force just below the centre of the pulleys. The rods M are for the purpose of stripping off any tow or short fibres of flax which may have remained between the heckle pins after they have passed through the flax; and as the pulleys K revolve, the rods M are pushed back into their former position by sliding against the guides N, until they reach the upper side of the pulleys, when their weight overcomes the centrifugal force; and they remain drawn back until again thrown out below the centre to strip the tow off the heckle pins. There are also a series of iron teeth OO attached to the inside of the leather straps B, which act as drivers to the straps, and keep the

heckle bars L always in proper horizontal position, by ensuring both the straps B being driven always at the same rate and without any chance of slipping; these teeth are driven by the teeth of the driving pulleys KK, and the small pulleys JJ at top are also notched to receive them, the inner faces of the teeth O being rounded off to the proper curve for forming part of the circle of the upper pulleys JJ in passing over them.

The main difficulty to be encountered in the heckling process has always been to obviate the large amount of waste that is made in the operation; and though heckling machines have been constructed in great variety, the same drawback of excessive waste has attended each, the proportion of the "dressed line," or finished flax after the heckling, being as small as only 40 per cent. of the flax put into the machine in the lower qualities of flax, but ranging in the better qualities from 60 to 75 per cent. Heckling machines are also sometimes made with double sets of heckles and holders, for the sake of economy of construction and working; and this may be an advantage in heckling the best kinds of flax. The lower qualities, such as Egyptian and some kinds of Baltic flax, require the least amount of heckling; whilst the best kinds of Flemish and Irish flax, which are strong in the fibre, are capable of being heckled to almost any degree of fineness.

In the next operation the dressed line or heckled flax, which has been obtained thus far in the form of a number of separate stricks of irregular thickness and quantity, is spread and drawn into a continuous sliver like a ribbon, by the combined action of a series of combs and drawing rollers.

Fig. 6, Plate 20, is a longitudinal section of the Long-Line Spreading Frame, so called because the distance between the receiving rollers A and the drawing rollers B is made long enough to take in the greatest length of fibre that has to be worked on the "long-line" system. The stricks of heckled flax are laid down upon the endless travelling feed sheet C, which carries the flax forwards to the receiving rollers A; and between these it passes on to the inclined bed of heckles or gills D, and then between the

drawing rollers B, through the doubling plate E, and between the delivery rollers F, which deliver the continuous sliver into the can G ready to be removed to the next process, the course of the flax through the machine being indicated by the arrows.

The heckle bars or gills D are supported at each end upon the slides H, as shown enlarged in Figs. 7 and 9, Plates 21 and 22; and they are traversed forwards towards the drawing rollers B by means of the upper pair of screws II revolving in one direction, and back again towards the receiving rollers A by the lower pair of screws JJ revolving in the contrary direction, each end of the heckle bar being inserted into a deep-cut groove in the screws I or J. This construction of machine is accordingly known as the "screw-gill" arrangement; and previous to its invention chains and other methods of propelling the heckle bars were employed. The heckle bars are carried forwards by the upper screws II till they arrive close to the lower drawing roller B, Fig. 7, when each bar in succession drops down at the end of the slides H into the groove of the lower screws J J; these are made with a much longer pitch of groove than the upper screws I, partly to economise the number of heckle bars, and partly to ensure the bar which has just dropped into the lower screw being carried back sufficiently out of the way, to allow the succeeding bar ample room to drop in the same manner. A cam K, Fig. 9, is placed at the termination of the groove in the upper screw I, so that if the heckle bar should happen not to drop by its own weight into the lower screw, the cam K will force it down, as shown in Fig. 10. The heckle bars are then carried back by the lower screw towards the receiving rollers A; and on each bar arriving close to the lower receiving roller, a cam L, Fig. 9, at the end of the lower screw raises the bar into the groove of the upper screw, as shown in Fig. 11, when the heckle pins penetrate the flax, and the heckle bar begins to travel forwards again towards the drawing rollers. The lifting cams L are continued through about one third of the whole circle, so as to support the heckle bar on a level with the slide H, until the screw I carries it a short distance along the slide, and thus to prevent it from dropping down again into the lower screw, which was a serious defect in the earlier screw-gills.

The screw-gills employed in the further process of preparing the flax for spinning are precisely the same in principle as those now described, only varying in their degrees of fineness. The system of screw-gill machinery shown in the drawings is called the "long-line" system, because by it the flax is worked the natural length of the fibre; and the machinery used for the cut-line and tow is just the same in principle, only shorter and finer to suit the length and fineness of the flax or tow operated upon.

The receiving rollers A, Fig. 7, travel at a surface speed of about 5 feet per minute, and the heckle bars about 5 per cent. faster so as to hold the flax in a slight tension. The surface speed of the drawing rollers B is from 15 to 30 times greater than the speed of the heckles, or from 70 to 140 feet per minute; consequently the fibres are combed or drawn between the pins, and the length of sliver delivered into the can G is elongated to about 15 to 30 times the length taken in by the receiving rollers A. One object of this operation is to lay the fibres parallel to one another, and also to prevent the long fibres from carrying the short fibres along with them and thus making an uneven sliver, which must produce uneven yarn. The upper of the drawing rollers B is made of wood, and is heavily pressed down by the links, levers, and weights M.

The flax is delivered from the drawing rollers B in a continuous sliver of ribbon-like form, from 4 to 5 inches wide, and four of such slivers are drawn by the machine, as shown in Figs. 8 and 9, Plate 22; these are then passed through the doubling plate E, and all four are rolled together into a single sliver of the same width by passing through the single pair of delivery rollers F. The doubling plate E, shown in plan in Fig. 8, has openings opposite each pair of drawing rollers at an angle of 45°, through which the slivers are passed, whereby they are caused to travel first at right angles to the line of delivery from the drawing rollers, and are afterwards turned again into the same direction towards the delivery rollers F, which deliver the final single sliver into the can G, Fig. 6.

The next operation is to re-draw and double again the sliver delivered from the long-line spreading frame; and Fig. 12, Plate 23,

shows the second Long-Line Drawing Frame. A number of cans G, generally eight, containing the slivers delivered from the spreading frame, are placed behind this drawing frame, whence the sliver passes over a high conductor N, in order to allow a considerable length to hang pendent and thus straighten out the creases made by pressing it down in the can G. The sliver then passes to the receiving rollers A, which are three in number, the object being to hold the sliver firmly and not allow the gills or heckles D to draw it beyond the surface speed of the rollers, which is about 6 feet per minute. The further operation of this machine is precisely the same as that of the spreading frame, the eight slivers being combed and drawn by the gills D and drawing rollers B, and then doubled by passing through the doubling plate E, and rolled into a single sliver by the delivery rollers F. The gills D however are finer and the rollers smaller than in the spreading frame. The speed of the gills is about $6\frac{1}{2}$ feet per minute, and the surface speed of the drawing rollers B and delivery rollers F about 130 feet per minute; and the length of the sliver delivered by the rollers F is consequently elongated to about 20 times the length taken in by the receiving rollers A.

The slivers from this machine are then taken to a third drawing frame, of precisely the same construction, but with still finer gills and smaller rollers; by this means the sliver is further elongated about 15 times, the object being to reduce it in width and thickness. From this third drawing frame the slivers are then taken to the roving frame.

Figs. 13 to 16, Plates 24, 25, and 26, represent what is known as the Screw-Gill Regulating Roving Frame, in which the delicate sliver of flax that has been produced by the previous processes is still further combed and drawn by gills and drawing rollers, and is then twisted into a roving and wound upon a bobbin.

This machine as a whole is perhaps the most complicated one used in spinning any kind of material, and has taken many years to bring it to the present state of perfection. The lower or regulating portion of the frame, by which the speed of winding the roving upon the bobbin is regulated according to the gradually increasing

diameter of the bobbin, is similar to that used in the cotton manufacture, where this system of machine was first introduced; but when so much of the machine as is used in the cotton manufacture is added to the screw-gill machinery, the two make what may be considered the most ingenious and perfect machine used in textile manufacture, and great ingenuity has been applied to overcome the numerous obstacles met with in perfecting this machine. The screw-gill part A, Figs. 13 and 14, is precisely the same as in the drawing frame last mentioned, only so much finer; for here the sliver is reduced to the smallest size previous to receiving the twist which changes it into a roving. The speed of the gills is about 6 feet per minute, and the surface speed of the drawing rollers B about 90 feet per minute, whereby the sliver is finally elongated about 15 times.

The special part of the roving frame, independent of the screw-gills and drawing rollers, is the regulating portion, situated in the lower part of the machine, which takes up the sliver as delivered by the drawing rollers, and after putting in the twist winds it upon a bobbin with a uniform but slight tension, not sufficient to elongate the delicate roving; and as each successive coil presents a larger diameter than the preceding, the speed of the bobbin has to be regulated or gradually increased for winding the roving, which is delivered at a uniform rate from the drawing rollers.

The bobbin spindles C C, Figs. 13 and 14, carrying the fliers D D, are driven at a uniform speed from the driving pulley upon the end of the main longitudinal driving shaft E, through a train of spur wheels driving the skew-bevil wheels at the bottom of the spindles C. The screw-gills A and drawing rollers B are also driven at a uniform speed by means of a change pinion on the end of the driving shaft E, through the intermediate wheel F working into the wheel G on the end of the top cone shaft H. The lower cone K, Figs. 15 and 16, receives its motion from the upper cone H through a strap L, which is made to travel longitudinally along the cones by means of a chain M passing over a pulley, with a weight hung at the end sufficient to draw the strap guide along two slide rods that extend the length of the cones or about 2½ feet. The speed of the lower cone is thus varied according to the diameters of the cones at

the point where the strap may be working. The advance of the strap guide is governed by an escapement motion acted upon at each vertical reciprocation of the bobbin lifter N. The bobbins O O run loose upon the bobbin spindles C, and are themselves driven in the same direction as the spindles C through the intervention of the regulating gearing and the skew-bevil wheels carried by the bobbin lifter N.

Upon the driving shaft E is keyed a mitre wheel I, Fig. 16, which drives two mitre wheels mounted in the disc of the spur wheel P; and these again drive another mitre wheel J running loose upon the driving shaft E. A spur wheel R upon the boss of the last mitre wheel J drives the train of spur wheels indicated by the dotted lines in Fig. 15; these are mounted on the jointed rocking frame S, Fig. 14, and communicate motion to the longitudinal shafts in the bobbin lifter N, which carry the skew-bevil wheels that gear into the bobbin pinions. The bobbins OO are thus caused to revolve in the same direction as their spindles C, but at a somewhat slower speed. If the disc wheel P were not allowed to rotate at all, the bobbins O would be driven like their spindles at one uniform speed; and if the disc wheel P were driven at the same speed as the driving shaft E, no motion whatever would be communicated to the train of wheels which drives the bobbins O: therefore by regulating the motion of this wheel P any required speed can be communicated to the bobbins. A pinion on the shaft of the lower cone K gears into a train of spur wheels and pinions, so as considerably to reduce the speed at the pinion T which gears into the disc wheel P, thereby governing this wheel in accordance with the speed imparted to the lower cone. The rotation of the mitre wheel I keyed upon the driving shaft has a tendency to drive the disc wheel P at a considerable speed, so that the lower cone K is required to retard instead of actually driving it.

When the end of the roving is threaded through the flier D and then attached to the bobbin shank O, Fig. 14, the flier being fixed upon the spindle C will first put the twist into the roving, according to the number of revolutions, generally from $1\frac{1}{2}$ to 2, which the spindle makes for each inch of sliver delivered by

the drawing rollers B. Then the speed of the bobbin must be so much slower than that of the flier as to enable the flier by its greater speed to coil upon the bobbin the length of roving delivered by the drawing rollers. When one coil of roving has been laid upon the shank of the bobbin, its diameter is increased by double the thickness of the roving; and therefore before the next coil is wound on, the speed of the bobbin must be increased in proportion to the increased diameter. This is effected by each ascending and descending motion of the bobbin lifter N releasing a paul, which allows the strap L to be drawn along the cones H and K to a different diameter, and thereby varies the speed of the pinion T gearing into the spur wheel P. By this means the roving is wound upon the bobbin with an equal amount of tension and consequently a uniform thickness throughout the entire length wound. The different thicknesses of the roving, and consequently varying diameter of the bobbin when the coil is made with a thicker or thinner roving, are allowed for by the fineness of the teeth in the ratchet wheel of the escapement apparatus. The bobbin lifter N is counterbalanced by the weight U, Fig. 14, and the vertical reciprocating motion is given to it by means of a mangle wheel with pinion and rack V, driven from the lower cone K, so as to impart a gradually decreasing speed to the reciprocating motion of the bobbin lifter in accordance with the increasing diameter of the bobbin as the roving is wound upon it. These variations in speed can be so nicely adjusted that the bobbin will take up the whole length of the roving wound upon it, amounting to several hundred yards, without any perceptible difference in tension between the first coil and the last.

Figs. 17 and 18, Plates 27 and 28, represent a section of a Tow Carding Machine. The tow frequently contains a considerable quantity of dirt and boom that has been left in the flax by the scutching machine. This is principally removed from the dressed line in the heckling process, but is thrown down with the tow or shorter fibres of flax which are combed out by the heckles. The tow carding machine is intended to separate the dirt and boom

from the tow, and deliver the fibre in an even sliver ready for the drawing frame.

The large carding cylinder A, Figs. 17 and 18, is 2 ft. 7½ ins. diameter, and is made of cast iron and covered with beech lagging set with finely ground and hardened steel teeth. The tow is laid upon an endless feed sheet B, which carries it forward to the feed roller C. Under the feed roller is a cast iron shell, the upper edge of which is carried up into the angle formed by the carding cylinder and the feed roller; and as the tow is slowly carried forwards by the feed roller at a rate of about 2 feet per minute, it is caught by the teeth of the carding cylinder A, which runs at about 300 revolutions per minute or 2500 feet per minute speed of circumference. The teeth of the cylinder A throw the tow against the worker D, which is a slowly revolving roller, running at a surface speed of only about 100 feet per minute, and covered with needle-pointed teeth set in strong leather. The teeth have a keen bend, as shown enlarged in Fig. 18, and carry the tow round towards the iron bar E, the upper edge of which is polished. The tow is then caught by the stripper F, which is clothed in a similar manner to the carding cylinder A, and runs much quicker than the worker D but slower than the cylinder A, having a surface speed of about 1500 feet per minute. The teeth of the carding cylinder then strip the tow from the teeth of the stripper F, and carry it forwards to a second pair of workers and strippers of exactly similar construction to the first, where the same operation is repeated for further cleansing and combing the tow.

The carding cylinder next carries the tow forwards to the doffer G, which is clothed with finely ground wire teeth set in leather, and moves very slowly at a surface speed of only 150 feet per minute. The tow is combed off the doffer by a comb I, Fig. 18, carried upon an oscillating arm worked by the crank shaft J, and it passes forwards to the feed roller H provided with an edge-plate or shell similar to the first feed roller C, and running at the same surface speed as the doffer G, feeding the tow again on to the carding cylinder A. As the speed of the carding cylinder is so very much greater than that of the doffer and feed roller, a further combing

action takes place upon the tow, by the teeth of the carding cylinder combing out the fibres, which are partially held between the teeth of the slow moving doffer and of the feed roller. The carding cylinder then carries the tow forwards to the second and third doffers K and L, where the final combing of the fibre takes place; and from these doffers the tow is combed off as before by the combs H, where it is divided into three slivers, and passed forwards to the two pairs of rollers M and N, in connection with which is a doubling plate provided with angular openings, as previously described in the spreading frame. The last pair of rollers N N deliver the slivers of tow into cans ready to be taken away to the drawing and roving frames. It is usual to place a gill drawing apparatus in connection with the carding machine, so as to perform the first drawing operation at the same time, immediately upon the slivers of tow being delivered from the last pair of rollers N N; and this arrangement has been adopted as an improvement.

The action of the teeth upon the tow in the carding machine ought to be of a combing character, and in order to get this action the tow requires to be held up to the points of the teeth, which is effected in the improved carding machine shown in the drawings by means of the edge-plates E E, Figs. 17 and 18, inserted between the workers and strippers. The tow accumulates upon the worker D with its keen bent teeth, and is taken off by the stripper F; but the edge-plate E binds the tow into the angle between the two rollers and holds it up to the teeth of the stripper, thereby causing an amount of friction in the passage of the tow, and enabling the stripper by its quicker motion to comb out the fibres. In the ordinary carding machines, without these edge-plates between the workers and strippers, the tow is plucked in patches from the worker by the stripper, sometimes in such quantities as to roll up the tow, and in this state it is carried back to the carding cylinder, thus breaking the fibre and making uneven work. Carding machines have for a long time been made with cylinders as much as 5 feet diameter, and a considerable number of pairs of workers and strippers, say from six to eight or even nine pairs; but in these

the work produced is in no way superior, and a much larger amount of waste is made and more power used. Wooden guards P P, Fig. 17, are fixed in different positions round the circumference of the carding cylinder, for the purpose of directing the currents of air caused by the rotation of the cylinder so as to disturb the tow as little as possible in its passage between the points of the teeth of the several rollers running in contact with the carding cylinder, in order thereby to avoid waste and imperfect work. The teeth of the doffers G, K, and L, are kept clean by the brushes R R driven in the opposite direction.

The after processes of drawing and roving the tow slivers as delivered from the carding machine are precisely similar to those in the long-line preparation already described, the drawing and roving frames for the tow being adapted to the shorter fibre to be worked. Several kinds of gills have been introduced for preparing tow, but none have proved an improvement upon the screw-gill, which is now almost universally used in flax machinery. The process of combing tow by a combing machine, after carding it, is carried on by two or three eminent spinners, but the cost is out of all proportion to the quality of yarn produced; and the tow thus prepared is only used for making sewing thread, to which it has been successfully adapted.

The last process in the manufacture of yarn is the spinning; and in Fig. 19, Plate 29, is shown a transverse section of rather more than one half of a wet Spinning Frame.

The cylinder A drives the spindles B, which carry the fliers for spinning the yarn, at a uniform speed of from 2000 to 4000 revolutions per minute, the speed being adjusted according to the weight and quality of yarn produced. C are the receiving rollers, and D the drawing rollers, which are called the back and front pair of rollers respectively; and the difference of speed is usually from 8 to 10 times, thus drawing out the roving to about one tenth of its size. The upper roller of each pair is pressed against the lower by the saddle and weighted lever E. The hot water trough F through which the roving passes is placed with its edge as

near as practicable to the bite of the receiving rollers C. The bobbins G from which the roving is supplied are placed above, and the roving is held down in the water by strips of wood H faced with sheet brass. A splashboard H is fixed in front of the spinning frame, to prevent the spray from the wet yarn being thrown upon the attendants.

The lower of the two drawing rollers D is driven by a train of wheels from the main driving shaft A at a uniform speed of from 100 to 200 feet per minute of the circumference, so that the fliers make from 20 to 40 revolutions for each foot of yarn delivered by the drawing rollers; and this additional amount of twist put into the wet sliver converts the delicate roving into a strong yarn. The yarn bobbin is loose upon the spindle B; and as the length of yarn given out by the drawing rollers is very much less than the length which the flier would wind upon the bobbin if the latter were stationary, the bobbin is simply dragged round by the flier in the same direction as the spindle B, without requiring any regulating gearing for driving the bobbin as in the case of the roving frame, since the yarn is too strong to be elongated or injured by the tension necessary to drag the bobbin round. In order to keep sufficient tension upon the yarn whilst winding upon the bobbin, so as to prevent "snarls" in the thread, a cord is pressed against a groove in the bottom flange of the bobbin, the friction of which retards the bobbin and produces the required tension upon the yarn: one end of this cord is fastened to the inner edge of the bobbin lifter J, and the other end hangs pendent with a weight through a notch in the outer edge of the bobbin lifter, which is notched along its entire length; thus the amount of friction upon the bobbin can be varied as desired by shifting the cord into a different notch, thereby varying the length of the arc of contact of the cord with the bobbin flange. The bobbin lifter J is raised and lowered at a uniform rate by the lever K worked by the cam L, which is driven from the main driving shaft A.

The important point in a spinning frame is to have good rollers. The receiving rollers C and the lower of the drawing rollers D are made of hard brass, and all three are very carefully fluted longitu-

dinally with flutes that have a round top and bottom, so that the roving as it passes through the receiving rollers may not be unevenly crushed, which would cause the fibre to break down in the drawing process. The drawing rollers D have the upper or pressing roller made of soft material, usually boxwood, but the warm water used in the process is very destructive to the wood; gutta-percha also has long been tried, but if not well purified from sand or earthy matter it is apt to wear away the brass roller.

Scarcely any improvement has been made in the spinning frames for a great number of years, and they are practically the same as employed a few years after the introduction of wet spinning, which so completely revolutionised the flax manufacture. The heat of the steam from the hot water troughs and its condensation in the spinning room render this part of the manufacture anything but agreeable to the attendants, especially where the most strict sanitary rules are not enforced: a drawback to which the flax manufacture will most likely have to submit, until some other vegetable fibre that does not require wet spinning can be found to take its place.

The PRESIDENT remarked that they were greatly indebted to Mr. Greenwood for his very interesting paper just read, which had been kindly prepared by him for the present meeting of the Institution in Dublin, in compliance with the special request of the Council, as the subject was one of particular interest and importance in Ireland.

Mr. GREENWOOD exhibited in action one of the screw-gill machines of the make employed for drawing silk, in order to show the construction and working of the screw-gill; and he explained that the machine employed in the case of flax was exactly similar in construction, only larger and coarser in the pitch of the gills and combs, and the silk-drawing machine now exhibited was without

the angular doubling plate by which the several slivers of flax were directed into the same line and passed together through the delivery rollers so as to be rolled into a single sliver.

The PRESIDENT enquired what was the cost of a flax mill fitted up with a complete set of the machinery described in the paper, in comparison with the cost of mills for spinning cotton.

Mr. GREENWOOD replied that the cost of the mill was generally reckoned at so much per spindle of the spinning frame; and about twenty spindles were required in the spinning frame to absorb the work of one of the spindles in the long-line roving frame; and one spreading and two drawing frames were required to feed one roving frame of fifty spindles. Including the whole cost for the set of machinery, steam engine, shafting, and building, a flax mill might be put up for about £4 per spindle of the spinning frame. The spinning frames themselves were worth from 16*s.* to 25*s.* per spindle, according to the degree of fineness of the yarn to be spun, some being made with only 2 inches pitch from centre to centre of the successive spindles, and others as much as 4 or 5 inches pitch. A cotton spinning mill was very much cheaper than a flax mill per spindle of the spinning frames, but he could not state the difference of cost. The weight of thread produced per spindle was however much greater with flax than with cotton, and the material itself was also more valuable.

Mr. W. RICHARDSON said that the cost of machinery for spinning cotton varied according to the counts of yarn to be spun. For medium numbers, say from 30 to 40 hanks to the pound, a large mill had been built and fitted with machinery during the crisis caused by the American war for a total cost of 14 shillings per mule spindle.

The PRESIDENT enquired where the China grass was grown from which the sliver that was exhibited had been produced, and what sort of plant it was.

Mr. GREENWOOD replied that the China grass was simply a rank weed or nettle, similar to the common nettle of this country but growing to ten times the size, and indigenous to China, Java, the East Indies, and some other countries. The interior of the plant

contained the fibre, and the outside rind and green matter had to be removed. It was produced in the largest quantities in China, where it was woven from the split fibre without being spun. It was also used for ships' cordage, of which some very good samples had been seen in this country in the Chinese junk that lay in the river at London some years ago. If there were a regular business demand for China grass it could be supplied from Java at £35 per ton in London or Liverpool, and he had no doubt that in a few years' time it would hold a very important place among textile fabrics. He showed the process of drawing the fibre into slivers in the machine exhibited from the partially prepared state in which the material was supplied to the market; and stated that in the form of sliver it was sold to the worsted and silk manufacturers, for mixing with those materials, and could be spun quite well by itself without any difficulty, forming a most useful material for dresses. China grass was also grown in Algeria, and he believed in the south of France; but it was of smaller size in those cases, and the best was from China and Java, the plant requiring a hot sun and humid atmosphere for its full growth. The Emperor of the French had offered to import it free of duty into France for the trade, if the French manufacturers would use it.

The PRESIDENT enquired whether the common nettle of this country had been tried in the same manner as the China grass, and whether it contained fibre that could similarly be made use of.

Mr. GREENWOOD replied that the common nettle of this country also contained fibre that could be spun like the China grass; but it would be too dear to be made use of practically, because there was not a sufficient supply of fibre in the plant to make it of any commercial value, and moreover there was more difficulty in extracting the fibre from the small stem of the common nettle than from the large stem of the China grass.

Mr. W. E. NEWTON thought it seemed strange that China grass, which could be obtained at considerably less than half the cost of flax, should not be more generally used; and he enquired whether there were not some practical difficulties connected with the working of that plant, which did not exist in the case of the flax plant. He

had heard that with China grass there were some peculiar difficulties in the way of getting the fibre from the rough plant. Many attempts had been made to get materials for spinning from other fibrous plants, such as the common nettle and other plants growing in this country; but the difficulty had hitherto been almost insurmountable of getting the valuable fibre away from the woody part of the plant. The common stinging nettle indeed, which was indigenous to Ireland and Great Britain, contained a fibre as fine as that of the flax plant itself, or perhaps even finer; but it would be impossible to obtain a sufficient supply of the plants from the hedgerows and highways, and it would not be worth while to lay out land specially for growing nettles. The same objection arose in the case of the manufacture of paper, which might be made out of almost any weeds, but could not be produced commercially from such sources, because it was not possible to procure a sufficient and regular supply of the weeds for this purpose. A great deal had certainly been done already with regard to China grass, and Messrs. Marshall of Leeds had carried on an extensive series of experiments with it, and had succeeded at last in producing a pretty good yarn; but there seemed to be still some inconveniences and difficulties remaining, which prevented the China grass from being more generally adopted, and he would be glad of some further explanation in reference to this subject.

Mr. GREENWOOD said that about fifteen years ago Messrs. Marshall endeavoured to bring the China grass into use for yarn, and produced a considerable quantity, which was afterwards manufactured into a kind of cambric handkerchiefs. The prices at which the raw material was sold were very irregular, on account of there being no regular demand for it. The plant grew in a sort of jungle, and was cut down by the natives; and by what process the bark was stripped off in the first instance he did not know, but believed it was done by hand by the Chinese, as the material was very extensively used in China. It was imported into this country in long stricks of fibre of a brown or dark kind of cream colour, and when prepared and dressed was easily bleached. If the fibre were intended to be dyed, it was much better for this to be done without

bleaching. The processes of preparing the fibre, which was very stubborn and strong, had been attempted in a variety of ways; but it appeared that almost the only thing it required was washing with plenty of soap and warm water, in order to reduce it to a fine soft silky state. After being well pounded in soap and water the material was laid out to dry, preparatory to splitting. The splitting was done by spreading out the dried material in a layer about 15 inches wide and $1\frac{1}{2}$ inch thick, and it was then perforated by a number of fine sharp points fixed on a board, which had a slight shogging motion given to them of about 1-8th inch in order to assist the pins in splitting it up into its separate fibres. It was afterwards passed through a combing machine similar to a wool combing machine, in which it was combed out and delivered in tufts of about 9 or 10 inches length of fibre and subsequently converted into the form of a narrow sliver. In this state the China grass was supplied in large quantities to Bradford, where it was mixed with wool in the sliver, and gave to the wool what was called a spinning quality. Formerly silk was used for that purpose, the object being to spin out wool to a very much finer thread than it would spin to alone. The compound thread thus spun was used in Paisley for making beautiful tartan dresses, in which the great aim was to get the dress as light as possible: when silk was mixed with the wool sliver the tartan was one third lighter than if made of pure wool; and China grass seemed to offer nearly the same facilities as silk for combination in this manner with wool, and at only about one fourth of the price of silk, the sliver of China grass being sold in Bradford at about 3*s*. 6*d*. per lb., or even less than the cost of wool, whilst the cost of silk was about 15*s*. per lb. The China grass could be spun either pure or mixed, and when afterwards woven with silk warps it produced some of the finest fabrics that had been seen, giving them a kind of transparent glassy appearance in the sun which could not be obtained by any other material at present known of. All the difficulties in preparing the sliver seemed now to be entirely overcome; and without carrying the manufacture any further than the state of sliver, an enormous quantity of this could now be sold. It was indeed a cheaper fibre than any other, considering

the degree of fineness, and he had no doubt that in a few years it would be a very important textile material in this country. The reason why Messrs. Marshall's endeavours to spin the China grass had not proved altogether successful was he believed that they had only tried spinning the fibre wet, in the same manner that flax was spun; but the dry process was now found to be the only one by which the China grass could be spun. The effect of wet upon the fibre was clearly shown by taking a small roving of the China grass in the fingers whilst dry, when a breath would almost blow it apart into its original separate fibres; but if the same roving were wet with nothing but cold water and slightly twisted together, it would require considerable force to break it, and this was the difficulty in spinning the fibre wet. An examination of the China grass showed that each fibre was perfect in itself, and could not be split up *ad infinitum* like the flax fibre. In this respect it was like wool, and consequently could be spun very easily indeed, provided the spinning were done dry.

Mr. J. WHITLEY enquired what was the comparative strength of the yarns of China grass and of ordinary flax.

Mr. GREENWOOD thought the China grass was rather the stronger, and he had had some samples of sewing thread made from it, which compared favourably in point of strength with the ordinary linen thread. In respect to wearing qualities he believed it was considerably more durable than flax.

The PRESIDENT enquired whether any comparison had been made between the strength of handspun flax and that spun by machinery.

Mr. GREENWOOD thought the handspun flax was a little stronger, the fibre being better preserved in spinning by hand than by machinery.

The PRESIDENT enquired what improvements were at present considered to be needed in flax machinery, or whether it was thought to have been now brought into a state of such practical perfection as not to require any further material improvement.

Mr. GREENWOOD replied that the machinery was of course still imperfect in some respects, but he did not see at present how it

was to be made more perfect; within the last few years a little had been done towards improving it, but not much, and there did not appear to be any very important improvements remaining to be effected. Since seeing the process of preparing the China grass fibre, his impression was that finer qualities of flax might be prepared in a similar manner, and he was now engaged in making some machinery for that purpose. The main object now to be aimed at in the flax machinery was to get rid of the heckling machine and the spreading frame: in the heckling machine a waste of the flax was occasioned by the process of heckling, and in the spreading frame the operation of laying down the stricks of flax for feeding the machine was still done by hand, and was therefore liable to be performed carelessly and irregularly. In the preparation of the sliver of China grass that was exhibited these two processes had been entirely avoided, and the sliver was delivered in one process direct from the stricks of crude fibre by means of a combing machine of peculiar construction, in which the combs were very fine and the pins were presented at an acute angle to the surface of the sliver, thus clearing away all the short fibres and any small portions of bark or green substance which might by chance be left upon the fibre; and he thought the same treatment might be advantageously tried in the case of flax also.

The PRESIDENT proposed a vote of thanks which was passed to Mr. Greenwood, for his paper, and for the large number of excellent drawings and specimens that he had exhibited.

The following paper was then read:—

DESCRIPTION OF A PORTABLE STEAM RIVETTER.

By Mr. ANDREW WYLLIE, of Liverpool.

The Portable Steam Rivetter forming the subject of the present paper belongs to the steam hammer class, and performs the rivetting by a succession of rapid blows. Rivetting by a portable steam hammer is by no means a new idea, and several attempts have already been made to carry it out in a practical manner:- to mature such a machine however is not an easy task; and the portable steam rivetter now to be described is the result of many trials, frequent failures, and several improvements. As the portability of the rivetter depends upon its convenience of size and form as well as upon mere lightness, both of these considerations have to be kept in view in its construction; and consequently in irregular work it is not expected that the machine will ever be able to compete with manual labour; but by a simple modification of the steam hammer, the size of the steam rivetter has been so reduced that in straightforward work no more room is now necessary for rivetting by the machine than is required for hand-rivetting.

In steam hammers the piston inside the cylinder is connected by the piston rod to the hammer head, the latter being outside the cylinder and separated from the piston by the cylinder bottom with its stuffing-box; and the piston and the hammer head therefore travel each through the same space in the same time. The total length of a machine so constructed must therefore be equal to at least twice the length of the stroke, together with the sum of the lengths of the cylinder cover, the piston, the stuffing-box, and the hammer head. Moreover in order to apply such a machine to rivetting, it would generally be necessary to use a swage-tool for the head of the rivet,

especially if the head is to be of a snap form; and this would be an additional length to be added to those already named. The first step in the construction of the present portable rivetter was accordingly to get rid of a great deal of this length of machine.

Fig. 1, Plate 30, shows a general elevation of the rivetter and dolly in their working position, and Fig. 2 is a transverse section of the rivetter: Figs. 3 to 9, Plates 31 and 32, show the construction of the rivetter to a larger scale.

The rivetter is made with a swage-tool always, whether for flush rivetting or for snap-heads; and this swage-tool A, Fig. 8, is held in the front end of the cylinder B, and forms a loose plug or plunger not connected to the piston; while the piston itself C is an independent long bolt or hammer of suitable weight, traversing backwards and forwards like a shuttle in the cylinder B, and striking the end of the swage-tool A within the cylinder. By this arrangement the swage-tool or tool-head A remains almost stationary; and the total length of the machine is reduced to only the length of the stroke of the piston, together with the part struck of the tool-head, the length of the piston, and the thickness of the back cover; while the length required in an ordinary steam hammer for the stroke outside the cylinder and for the stuffing-box is here got rid of altogether. This is not only a saving of length, but also an economical simplification, and does away with the risk of breaking the bottom of the cylinder by an unobstructed stroke of the hammer; for the tool-head being entirely loose in the cylinder acts as a safety bottom to the cylinder. In rivetting, the tool-head simply follows the rivet as it is hammered up, and remains in contact with it; so that the workman has to look at an almost stationary tool-head instead of at a rapidly moving hammer, and he can therefore better adjust the position of the machine to the proper formation of the rivet head.

The principle of the hammer part of the rivetter having thus been arranged, the next point to be determined was the size of the cylinder, so as to render the machine portable and controllable, and of such a size that the workman may be able to hold it in its position independent of its mechanical fixings. In the back stroke of the

piston, the reacting pressure is upon the tool-head; but when the piston is being propelled forwards the reaction tends to push the machine back from its work, and the total amount of this pressure should not be more than the workman can readily withstand, as he might accidentally throw the whole pressure on himself by giving the machine steam when it was not fixed. It might at first be thought that in a horizontal push the force which the workman could exert would not be very great; but as the steam pressure is not continuous, but acting only during the forward stroke of the piston, and as the return stroke occupies probably three times as long as the forward stroke, the workman by a steady pressure of moderate amount can resist a momentary intermittent pressure of nearly four times that amount. The size of the cylinder for the horizontal rivetter, shown in Fig. 1, was accordingly fixed at $1\frac{1}{2}$ inches diameter, which with 60 lbs. steam gives a total pressure of about 100 lbs. on the piston. The stroke of the piston is about 15 inches, so that the full force of the blow will be about 125 foot-pounds; and this, with the hammer piston weighing $3\frac{3}{4}$ lbs., is found to be sufficient to make firm work with $1\frac{1}{4}$ inch rivets. The machine has not been tried on larger rivets.

The tool-head A, Fig. 8, which receives the blow from the piston and communicates it to the rivet, must not be made too heavy, otherwise its inertia would deprive the blow of much of its force. It must also be long enough to follow up the rivet, while still having sufficient length left in the cylinder to serve as a guide. These two conditions are met by making the tool-head hollow towards the piston, as shown in Fig. 8; and its weight is only from $1\frac{3}{4}$ to 2 lbs., or about half the weight of the hammer piston. The piston C has a long tapering end, which enters the hollow of the tool-head and strikes on the bottom of the recess. It was anticipated that the striking surfaces would soon be broken by the rapid blows of hard steel on hard steel; but it is found that the constant presence of steam prevents their overheating and mutual destruction, and in no instance have they been found to fail at present. Their durability however is only a question of time; and to retard the progress of destructive crystallisation, the piston and tool-head are occasionally

annealed by being brought to a red heat and slowly cooled, and then their striking surfaces are tempered in oil.

The face of the tool-head for flush rivetting is made slightly rounded, but nearly flat; for snap-rivetting it is formed into a cup of the required form. It is always easier to make a pan-head by the machine, that is a head which is the frustrum of a cone, than a snap-head, as the sides of the pan-head form a firmer centering for the machine. The tool-head has two or three grooves turned on the inner end for twine packing, as shown in Fig. 8, which is sufficient to withstand the very slight pressure of steam in the return stroke of the piston; the steam port D at the front end is only about 1-100th square inch in area, and the tool-head might therefore almost be left without packing.

In the distribution of the steam, as the piston has no projecting part outside, its motion cannot be made available for working the slide valve by external connections; and the first rivetter was made with inside tappet levers, moved by the piston coming in contact with them. Although these served the purpose very well, it was thought that, as the speed of the piston was sometimes above 2000 feet per minute when it struck the front tappet, such an action would be destructive to the machine, notwithstanding that the movement was effected by a very gentle taper upon the piston. The next machine was therefore made with an inside tappet at the back end only, and with a small steam port at the front end for moving the valve; and the return stroke of the piston being performed at a comparatively low velocity, the inside tappet can be worked at the back end with great accuracy and with little wear. Moreover it is necessary to retain the mechanical movement at the back end of the cylinder, in order to secure the requisite certainty of action for preventing the possibility of the piston ever striking that end of the cylinder.

The slide valve E is a piston valve, and is shown in its two extreme positions in Figs. 8 and 9. In the position shown in Fig. 8 the hammer piston C has uncovered the valve steam port F, and the steam which has been propelling the hammer piston can now act on the piston of the slide valve E, which is thereby moved forwards

into the position shown in Fig. 8, cutting off the steam at G from the chamber H of the back port and opening it to the exhaust K, and closing the front port D from the exhaust K and opening it to the steam G. In this position the steam chamber G has an opening to the front port D through a groove in the side of the slide valve, this groove being partly closed by the small regulating screw I, and the steam is thus admitted slowly to the front of the hammer piston. At the same time the back port chamber H and the back end of the cylinder are open to the exhaust chamber K. As there is then steam pressure on the front of the hammer piston, and a free exhaust behind it, the piston will move towards the back end of the cylinder; but at some distance from the end it comes into contact with the inside tappet J, Figs. 4 and 5, for which a recess is provided in the side of the cylinder, and the piston in passing pushes the tappet into the recess, as shown by the dotted line in Fig. 4. The tappet motion draws the slide valve back, and the openings of the steam passages are thereby reversed, as shown in Fig. 9; and the motion of the piston is changed to the forward stroke before it has come into contact with the back end of the cylinder.

The back port pipe L, Figs. 3 and 5, is the steam way to the back end of the cylinder, and connects it with the back port chamber H of the slide valve casing, Fig. 8. This pipe is screwed steam-tight into the valve casing, and at the back end it is packed with a gland, as shown in Fig. 5, which allows for the expansion of the tube. A separate tube is used for the sake of getting a simpler form for the cylinder casting, and in order to save weight and get a cleaner passage than if it were cast in one piece with the cylinder.

The back end of the hammer piston C, Fig. 8, is made of a curved shape to ease the shock of the blow upon the inside tappet J, Fig. 4. At the front end the body of the hammer piston in the first rivetter had longitudinal channels made in it, extending so far back that when the piston advanced to the fullest extent in following up the tool-head the body of the piston should not close the front steam port D: these channels were adopted in place of turning down the entire body of the piston, in order that the full

length of bearing of the piston in the cylinder might be preserved. In the improved construction of the rivetter however, shown in the drawings, the necessity for these channels is obviated by extending the front steam port D far enough forwards, as shown in Fig. 8, so that it is never entirely closed by the body of the piston.

The steam stop-valve is a small grid valve, with a spring to keep it on the face, and a spiral spring to close it; or a cock with a spring to close it. It is in a casing at the side of the steam chamber of the slide-valve, and is opened by a cord extending to one of the back handles M at the end of the cylinder. Any difference in the amount of opening of the steam stop-valve affects only the forward stroke of the piston and the force of the blow, the velocity of the back stroke being regulated by the set screw I in the steam groove of the slide-valve, Fig. 8, which determines the rapidity of the blows without altering their force. The steam is conveyed to the rivetter by a six-ply flexible tube of $\frac{3}{4}$ inch bore, with brass nozzles of $\frac{1}{2}$ inch bore. The exhaust pipe is $\frac{3}{4}$ inch bore at the nozzle, and a short length of india-rubber pipe of 1 inch bore is attached to carry the waste steam away.

The horizontal rivetter shown in the drawings consists of two parts, the rivetting cylinder and the holder-up: when in operation these two portions are locked together through the next rivet hole, as shown in Fig. 1, and in this form the portable steam rivetter is therefore called the "locking machine," to distinguish it from the other forms of the machine which are either permanently coupled or permanently separate. The locking pin N is attached to two short studs cast upon a nozzle O, Fig. 8, which is screwed on the end of the rivetting cylinder, being held from turning by the spring bolt P, Fig. 3, engaging in one of the notches Q upon the nozzle. The foremost of these studs R is mounted with a hollow screw and key S for adjusting the position of the locking pin to suit the gauge of the rivet holes; the other stud is a guide for the inner end of the locking pin. The locking pin is 5-8ths inch diameter, of steel, and the socket in which it is fixed forms a large shoulder, as shown

in Fig. 8, for butting to the plate that is being rivetted: this shoulder is so much in advance of the end of the tool-head that sufficient room is left for the projection of the head of the rivet, as seen in Figs. 1 and 10. On that part of the locking pin which is on the other side of the plates, there are a number of ratchet teeth, Fig. 13, and these lock with a catch T on the holder-up, by which means the two portions are held together during the operation of rivetting. The locking pin is made in two pieces, a head with two eyes which go on the two studs of the rivetting cylinder, and the pin itself which is cottered into this head, so that either a larger or smaller pin can be used as required.

The blow of the portable steam rivetter is so powerful that for horizontal rivetting a common dolly cannot be employed, as the rivet would never be brought up in the head. A spring dolly is therefore used, as shown in Figs. 10 to 13, Plate 33, and its action has been found very satisfactory. The dolly is in a spring box made of 3 inch boiler tube, on the front of which are the eye and locking catch T for connecting the dolly to the locking pin N of the rivetter. By entering the eye on the locking pin and forcibly pushing the dolly along the pin, the spring would be compressed and the catch T would engage in one of the teeth of the pin. But it would be very difficult to run the dolly up perfectly fair on the pin, and the locking catch might not engage securely with the tooth, and might be only on the point of the tooth, in which case the dolly would be driven off by the first blow of the rivetter, and the rivet would not be brought up in the head. To obviate this the dolly is made with a compression notch U at the back end, and a spring detent V in one of the handles W; and the workman holding the dolly by both handles places it on the ground, and by a sudden jerk compresses the dolly spring until the detent V lays hold of the notch and the compression of the dolly is thereby retained. The dolly is now lifted and entered on the locking pin, and the rivet is inserted and pushed home by the dolly, and the locking catch T lays hold of one of the teeth of the locking pin; as there is now no strain on the dolly, the catch T is not prevented from entering to the bottom of the tooth so as to obtain a secure hold of the locking

pin. By then turning the detent handle W, which is screwed into the dolly cap, the detent V is withdrawn; and the dolly being released, as shown in Fig. 10, presses upon the rivet with almost the full compression got by jumping it together on the ground.

During the rivetting the workman has only to keep the dolly true on the rivet head by a slight pressure sideways, and the strongly compressed spring causes it to press with great force on the rivet, and makes very sound work. When the rivet is finished, the locking catch T is disengaged by means of the lever X, and the dolly being released resumes its original condition, as shown by the dotted lines in Fig. 10. With flat-headed rivets the dolly is merely turned round on the locking pin, and the catch T is thereby thrown out of the tooth which is only on one side of the pin. The dolly is then removed from the locking pin for the purpose of being compressed again; the workman on the rivetting side has at the same time removed the rivetter to the next hole, and when the dolly is lifted up the locking pin is ready for it, and the same process is repeated.

It was originally intended to support the portable rivetter by a lanyard with sufficient slack to allow of a great range of the machine. Where it is convenient to have this it would no doubt be an advantage, as the lanyard would not require to be shifted or altered in length oftener than about once an hour for horizontal seams. It would be attached to the front of the machine, and should be of such a length as to suspend the machine 6 or 8 inches below the rivet holes, so that the workman would have to depress his end of the rivetter sufficiently to tilt up the point of the locking pin to the rivet hole, when the machine could be pushed home. It is found however that the rivetter can be worked without a lanyard, without much inconvenience to the workman. When the rivetter and dolly have been locked together, the workman is relieved from all the weight; and it is only in shifting from hole to hole that he has to carry the machine, which is easily lifted with one hand at the back end and the other at the locking pin handle S, Fig. 1. In the first machine there were handles at the front end also, but these were not needed and have been discontinued.

In Fig. 14, Plate 34, is shown an elevation of a vertical coupled rivetter, in which the rivetting cylinder B and the dolly Y are permanently coupled together by the coupling Z. This form of the rivetter is particularly suitable for rivetting ships' frames lying horizontally on the ground; and in this case the rivetting cylinder B is below, and the dolly Y at top. For shifting the machine when the rivet is completed, the dolly is compressed by a jerk as before, and the compression is retained by the detent until the machine has been removed to the next hole and the rivet inserted, when the detent is withdrawn, and the dolly holds up the rivet against the blows of the rivetter.

In the horizontal locking rivetter, the weight of the rivetter itself and locking pin is 45 lbs., and of the holder-up 34 lbs. The vertical coupled rivetter is a few pounds heavier, the holder-up not being altered in weight.

Mr. WYLLIE explained that the portable steam rivetter described in the paper just read was the invention of Mr. J. Mc.Farlane Gray, who was present at the meeting and had brought over one of the rivetters, which would be worked with steam during the conversazione to be held in the International Exhibition that evening, when the members would have an opportunity of witnessing its actual working.

Mr. GRAY exhibited one of the portable rivetters, and showed the mode of bringing it up to the work to be rivetted. He explained that the rivetter required no lanyard or other arrangement for supporting it in work, as its weight was carried whilst rivetting by the locking pin inserted through the adjacent rivet hole; and it was easily lifted from hole to hole by the two attendants, one of

them shifting the dolly while the other shifted the rivetter itself: the screw and key gave the means of altering the distance of the locking pin from the rivetter to suit the pitch of the rivet holes. With 60 lbs. steam the hammer piston gave about 300 blows per minute. He exhibited a specimen of plates rivetted together by the machine with $1\frac{1}{4}$ inch rivets, and afterwards slotted down the centre of the rivets, to show how completely the holes were filled by the rivets.

The PRESIDENT enquired how the working of the rivetter would be managed in rivetting at a ship's side, where there would be little room to work in.

Mr. GRAY replied that the man with the rivetter stood on a platform outside the ship's side, and the other attendant with the dolly on a platform inside, where the rivets were to be put in. The locking pin of the rivetter having been passed through the hole next to the one to be rivetted, and the dolly entered on the pin, when the hot rivet was inserted into the hole, the compressed spring of the dolly was liberated by the man on the inner side, holding up the rivet true and firm in the hole; and then the other man by pulling the string attached to the steam valve turned on the steam, and the rivet head was immediately completed by the blows of the rivetter. The locking pin was then instantly released by merely turning the dolly partly round upon the pin if the rivet head was flat, or by releasing the locking catch by the lever if the dolly had a cupped die; and while the rivetter and locking pin were shifted to the next hole by the man outside the ship, the other attendant inside compressed the dolly spring again, and was ready to slip it over the locking pin as soon as the latter was put through the next rivet hole from the outside. This was done so quickly that the shifting of the rivetter and dolly did not occupy more than about 8 seconds, and the act of rivetting occupied about 7 seconds, making about 15 seconds total for each rivet. He then showed to the meeting the facility with which the rivetter and dolly were coupled and uncoupled by the locking pin, and the rapidity with which they were shifted from hole to hole in a plate.

The PRESIDENT asked whether it was expected the rivetter could be worked as fast as to take only about 15 seconds for each rivet in ordinary working, as it seemed doubtful whether the men would be able to stand that rate of work as a regular thing.

Mr. GRAY replied that the machine was guaranteed to do one rivet per minute easily in ordinary straight work, and two or three per minute could be put in if there were any hurry about the work.

Mr. J. MURPHY enquired what was the comparative speed of rivetting by the machine as compared with hand rivetting.

Mr. GRAY replied that in rivetting straightforward work such as the sides of the Britannia tubular bridge one of these machines could put in a thousand rivets in a day of ten hours, being at the rate throughout of one rivet in 36 seconds. In a special trial of speed with the machine he had himself put in fifteen rivets in 3 minutes and 35 seconds or at the rate of 14 seconds per rivet; and on another occasion he had put in three rivets in 26 seconds by the machine. There was therefore no doubt that the rivetting could be done by the machine considerably faster than by the most expeditious hand work. The men who had worked the machine much preferred using it to being either the holder-up or the rivetter in ordinary hand rivetting; and the construction of the spring dolly caused the shock to the man holding up the rivet to be much less than in hand rivetting.

Mr. J. RAMSBOTTOM enquired what was the weight of the hammer piston in the rivetter.

Mr. GRAY replied that the hammer piston was $3\frac{1}{4}$ lbs. weight.

Mr. C. COCHRANE enquired what extent of area could be worked over conveniently with the steam rivetter without having to shift the steam pipe connections. He supposed a flexible steam pipe would be necessary for enabling the machine to work over a considerable area.

Mr. GRAY explained that the first and the last lengths of the steam pipe conveying the steam to the rivetting machine were flexible, and each about 10 or 12 feet long; the rest of the steam pipe was only $\frac{1}{4}$ inch gas pipe, which could be carried to any

distance that might be desired for conveying the steam from a stationary boiler; or a portable boiler with a shorter length of steam pipe might be employed if preferred.

Mr. J. FERNIE remarked that he remembered a portable steam rivetter had been constructed some years ago by Mr. Naylor, and he thought it would be very useful if they could be informed what had been the difficulties that had been met with in that machine.

Mr. W. NAYLOR said he had found many difficulties in working out the portable steam rivetter, and had not been able to succeed in bringing it to what he could consider a practical success; and only two or three of the machines had been constructed and put to work. One practical difficulty, which he thought would be found also with the machine described in the paper as well as with any other steam rivetting machine, had arisen from the rivets not being always perfectly at right angles to the plate: if the rivet came exactly square through the plate, the hammer might then strike it true and bring it home with a fair head; but if the rivet did not come exactly square through the plate, it would not be truly in line with the stroke of the hammer, and the hammer might turn it to one side and form the rivet head on one side. He had had one machine made with the hammer on a universal joint so as to move round, in order that if the rivet came through the hole not quite square the hammer could be turned so as to hit it fair and bring it straight again. There was also a practical difficulty in using a machine for such work as iron shipbuilding, where one portion of the ship's side was vertical and other portions slanting, and the bottom part was particularly difficult to get under with a machine. With the smaller rivetting machine that he had made the rivet was held up by a man with a lever dolly in the ordinary way; but with a larger machine he had employed a small steam cylinder for the purpose. The great difficulty however was to get rivetters who would use the machine, as the men thought they would do the work much better without the machine, and so save all the cost of it. If he had himself had the entire management of the work in all respects, he might perhaps have succeeded in performing it with

the machine: but he had been satisfied by the experience which he had had that under ordinary circumstances he should not be able to make the machine a commercial success so that it could advantageously compete with hand labour. There was no doubt that a portable steam rivetter would be a very valuable tool, if the difficulties that had been encountered could be overcome, so that the machine could be brought to bear practically for rivetting.

Mr. GRAY said he had contemplated the difficulties that had been mentioned; and as regarded that arising from oblique position of the rivet in the rivet hole, he did not think it existed to such an extent with the rivetter described in the paper as had been supposed, because the steam rivetter was intended to be used with machine-made rivets, which would have the rivet head truly square with the bolt. If therefore a rivet came through not square with the plate, it was not the fault of the rivet, but showed that the holes in the plates were not fair. The steam rivetter however acted with such force that the rivets were not required to be the full size of the holes, but considerably smaller rivets could be used, which were still made to fill the holes completely by the compression produced by the machine; and accordingly in working 1 inch holes with $\frac{7}{8}$ inch rivets the machine made a sound job of the rivet and filled the hole up at once. This allowed $\frac{1}{4}$ inch of slant in the hole, while still keeping the rivet square to the plates. Moreover the spring dolly for holding up the rivet pressed with very great force upon the rivet, so that the rivet must come through the plate square or very nearly square. Even if the holes were tight however, and the rivet got a little slant to one side, the machine had sufficient play to allow for this, as the locking pin passed loose through the adjacent rivet hole, which had the same effect as a universal joint in allowing of the amount of deviation that was needed to perform ordinary rivetting; while the rivetter itself, being only about 45 lbs. weight, admitted of being turned about almost as easily as a hammer. It had thus the advantage of affording as great facility for straightening a slanting rivet as in hand rivetting, provided of course that the workman noticed the rivet was slanting.

The application of the machine to snap rivetting was perhaps not entirely satisfactory at present, but it was very much better than he had anticipated; in the first trials indeed snap rivetting had been given up as hopeless with the machine, and it was not until lately that the machine had been tried again for the purpose with the ordinary round snap-heads. The machine had been employed with success upon pan-head rivets, which could be got hold of better by the die of the rivetter, and twisted by it slightly to one side or the other: but it was now found that even the snap-heads could be easily managed, and this was to be attributed he thought to the efficiency of the holder-up, which had been improved since the former trials.

With regard to the difficulties of getting the steam rivetter introduced on account of the prejudices of the men, he might mention that the first of the machines which had been made had been sent down to Messrs. Napier's works at Glasgow to be employed for rivetting up ships' frames lying horizontally in the yard; it was one of the vertical coupled rivetters, which was the form first made, and it was guaranteed to put in one rivet per minute in regular work. In the trial of it at starting he had himself put in fifteen $\frac{7}{8}$ inch rivets in 3 minutes and 35 seconds, which was considered so decided a success that two of the machines were ordered instead of one. At the same time he was urged to modify the construction in such a manner as to render the machine capable of being employed horizontally as a portable rivetter, for rivetting the ships' sides &c., because it was not worth while to use the vertical rivetter until the other form had been matured and made practically successful, so that the machine might be relied upon to be capable of doing a great part of the work at present performed by hand rivetting. He had accordingly completed the horizontal rivetter in the form described in the paper, which was sufficiently matured to be practically available and commercially profitable; and men were now ready to go out with the machine and undertake rivetting with it at such a cost as would make it well worth while to employ the machine in place of hand rivetting.

The PRESIDENT observed that the experiment referred to at his works with the first rivetter had given great satisfaction, as had been stated; but there had not been opportunity at present for putting to work the two new machines that had been obtained.

Mr. J. MURPHY considered the portable steam rivetter now described was a most valuable addition to the number of rivetting machines already existing, and thought it would be particularly useful in plating ships, where it was necessary to go to some height from the ground. The ordinary rivetting machines at present employed were of such a ponderous construction that they could not be moved, and the work had therefore all to be brought to them. The great advantage of the new machine was that it could be taken to the work; and from its portability and the simplicity of its construction he thought the objection of the men to using it would soon be got over. Even if the present rivetters refused to work with the machine, other men might he expected be got to use it with a little teaching; and he enquired whether it was necessary to employ skilled workmen to work the machine, or whether unskilled hands could not readily learn to use it. The same objections might be made to sawing and planing machinery, or to any machinery intended to supersede manual labour; but the use of such machines had long been successfully established notwithstanding all such objections.

Mr. GRAY said there would be no difficulty in employing unskilled labour for working the machines; if there were half a dozen machines to be worked at one place, one mechanic would be required who understood them and could keep them in order, while any intelligent labourer could work the machine. The construction of this rivetter was so simple that unless the parts were broken they could not be put together wrong; and duplicates were supplied of the working parts, to provide against breakage. If the ordinary large rivetting machines had proved a commercial success, he thought that ought equally to be the case with the new portable rivetter, because he was satisfied that by means of the portable machine more work and of equal quality could be done with the same number of men and at less than half the expense

for machinery. For a fixed rivetting machine required one man at the crane for lifting the piece of work to be rivetted, another man to guide the work, a third to supply the rivets to the machine, and a fourth to work the machine. If the same number of men were employed with the portable rivetter, two to each rivetter, they would be capable of working two of the rivetters, the cost of which would be less than half that of a fixed machine, while he doubted whether any fixed machine could put in as many rivets in a given time as could be done by two of the portable rivetters. The principal use of the portable rivetter was for such work as the Britannia tubular bridge, in which it could perform the whole of the rivetting; and if in shipbuilding, where a great proportion of the surface was slanting, some places were met with where the machine would not be convenient to use, he did not think that constituted an objection to its employment for the general rivetting work of the ship. The case of the portable rivetter was in fact very similar to that of the sewing machines now so largely employed, which were used with great advantage for a long run of straightforward work, but left a few special parts to be finished by hand work.

Mr. J. WHITLEY enquired what was about the cost of the portable rivetting machine.

Mr. GRAY replied that the cost of one of the rivetters complete with a set of duplicates was about £60, but they were expected to be less expensive when they had come into general use.

Mr. J. MURPHY enquired what was the relative cost of rivetting by the machine and by hand labour.

Mr. GRAY replied that the men who had had experience of the working of the portable steam rivetters were willing to go out with the machines and keep them in order and to do work with 1 inch rivets for a payment of 1*s.* per hundred rivets; and there would also be the cost of a man to shift the dolly for holding up the rivets, and two boys in attendance, making the whole cost not more than 3*s.* per hundred for 1 inch rivets; and at this rate of payment the men expected to double their present wages. The cost of rivetting similar work by hand was about 12*s.* per hundred rivets.

The PRESIDENT enquired whether there had been any failure yet of any of the working parts in the trials made with the rivetter.

Mr. GRAY said that the parts which were expected to wear out first were the piston and the tool-head, as these had all the work upon them in rivetting. In order to test the durability of these parts, one of the rivetters had been put to work with only a small piece of hard steel between the rivetter and dolly, delivering its full stroke on the dolly, and hammering away at the rate of 300 blows per minute without any intermission: after working for about fifteen hours the compression catch piece at the back end of the dolly dropped off, a part not then in use but shaken off by the mere shock of the blows. In actual work this shock was either absorbed almost entirely by the plates, or was transmitted through a hot rivet, and therefore had not this destructive effect. The experiment was continued until the piston was broken across at a packing groove, after having given about 400,000 blows. The pistons were now made without any grooves and were therefore more durable. The tool-heads were now the first parts to give way, and required to be renewed as in any other rivetting machine. The pistons and tool-heads were easy to replace, and duplicates of them were supplied with each machine.

The PRESIDENT moved a vote of thanks to Mr. Wyllie and Mr. Gray for the paper, which was passed.

The following paper, by Mr. Charles Hodgson, of Portarlington, Managing Director of the Derrylea Peat Works, communicated through Mr. G. Arthur Waller, was then read:—

ON THE MANUFACTURE OF COMPRESSED PEAT FUEL.

By Mr. CHARLES HODGSON, of Portarlington.

Improvements on the ordinary mode of preparing Peat Fuel have attracted much attention for many years. All who have considered the subject have felt that the chief difficulty lay in drying the wet peat obtained from the bog; and to accomplish this numerous plans have been tried, for expressing the water from the saturated peat by power, or evaporating it by artificial heat or air currents after having moulded the material into some brick-like form. But none of these methods have been practically successful, because they required that great masses of wet peat should be manipulated before drying; and because air-drying the moulded blocks proved too slow, and artificial drying far too costly an operation.

A system which had in it the elements of success and differed essentially from all previous plans was however proposed by Groynell and others about fifteen years ago. Their idea was to cut peat in the ordinary way and air-dry it to the extent that was possible during the summer in the climate of Ireland; then to grind it and complete its desiccation whilst in a state of powder; and subsequently to compress it in a machine provided with a reciprocating ram, and several moulds capable of being brought successively under the ram. A beautiful sample of hard fuel was thus obtained, but unfortunately the quantity made was limited to samples; for the action of these machines with their moving moulds was complicated, and the strain on the parts was so severe that breakages were of constant occurrence. In addition to these difficulties it was found that the hard and perfect article desired could only be produced when the ram was made actually to stand still at the furthest point of its stroke, and retain the block of peat

under pressure for several seconds. The longer it was thus held without being allowed to expand, the more perfect the block became; but if the pressure was removed at once, as in the case of an eccentric of uniform motion, however slow, the elasticity of the peat was not overcome, and more or less of cracking and abrasion would take place within the next few hours. But in the course of these experiments, tried in 1850 to 1853, the fundamental difficulty of obtaining a large and constant supply of dry peat was never even encountered, because the compressing machinery never stood the test of actual continuous work. Even had these machines been then perfected, it would soon have been found that to grind peat already fit for fuel, and afterwards compress it, would be ruinous in cost; and that to dry artificially peat taken wet from the bog would absorb all the fuel produced and leave none for sale.

The practical difficulties which beset all early attempts in the manufacture of peat fuel have now however been overcome by the system and machinery employed at the Derrylea Peat Works, near Portarlington, where the manufacture of compressed peat fuel has been regularly carried on for some time, upwards of 5000 tons of the compressed peat having been already made there and sold in various parts of the country. The system in use at these works is based on the principle that the drying of the peat is the main difficulty of the manufacture; and this is accomplished by operating continually on thin surfaces of disintegrated peat, instead of on compact sods or blocks; while the compression afterwards employed is used only as a means of rendering the already prepared peat transportable and marketable. The system of drying by thin surfaces is also further carried out by the plan of obtaining the peat from the bog by successive harrowings and scrapings.

In Fig. 1, Plate 35, is given a general plan of the Derrylea Peat Works, showing the mode in which the works have been laid out. The portion of bog at present operated on for the purpose of obtaining the partially dried peat powder or "mull," which forms the raw material for manufacture, is about 1200 yards long by 100 yards wide, covering 24 statute acres. A deep head drain AA cuts off

this area from the remainder of the primitive bog; and it is itself drained by transverse covered shores about 20 yards apart, as indicated by the dotted lines BB, running from this head drain to another main drain CC parallel to it, which forms the opposite boundary of the patch, and runs in fact along the edge of the bog and falls into the natural drainage of the district. The covered shores BB are simply and cheaply formed by cutting drains in the bog about 4 feet deep and 2 feet wide at the top, sloping in the sides so as to leave the bottom 1 foot wide; in this bottom a square groove about 6 inches in width and depth is formed with a tool adapted for the purpose, called a "double-winged slane." Sods cut square from the top of the bog are now placed across the top of this groove; and the peat excavated from the drain is again filled in and levelled on the surface. These drains cost about 2*d.* per yard, and are very effective; they have been used in many parts of Ireland in draining for agricultural purposes.

A railway of the 5 ft. 3 ins. Irish gauge, formed of 36 lbs. T rails well fished at the joints, runs along the centre of this drained piece of bog, being 50 yards distant from each of the main drains AA and CC. It is laid on sleepers of native timber, and carries an 8 ton locomotive without requiring any ballast on the roadway. On these rails runs a six-wheeled truck, 24 feet long, substantially built; and across this truck is laid a square box-lattice girder, 300 feet long, reaching over the entire width of the drained ground, as shown in Figs. 2 to 5, Plate 36. This girder is formed of $1\frac{1}{2}$ inch angle iron at the corners, latticed on each of the four sides with flat bar iron $1\frac{1}{2}$ inch wide by $\frac{1}{4}$ inch thick, leaving 2 feet spaces; it is 6 feet square at the centre, where it rests on the truck, and tapers to 1 foot square at each end, and is stayed perpendicularly and laterally by wire rope stays DD set in taut. This apparatus is propelled by a 6 horse power portable engine, geared down 5 to 1 to the wheels; and it is worked at the rate of about 4 miles per hour, with its great arms stretching over the bog at each side to a distance of 150 feet. To these are attached ten or twelve harrows, each 6 feet square, which by repeatedly passing over the ground scarify it and pulverise the surface to the depth of from 1 to 2 inches. This operation is

performed during any moderately fine weather; and in the mornings and during the day the light powdered surface, which readily dries to a certain extent, is wheeled by men to the side of the railway and wagoned into the works for manufacture.

In dry weather the upper surface of the bog, thoroughly drained as it is, will always contain much less water, perhaps less than half what the general mass retains; and as by this mode of operation a fresh upper surface is being daily exposed, it follows that peat in the most favourable state for drying is being constantly operated on. As soon as the harrowing begins, rapid air-drying takes place, and a very large portion of the water which is not removed by drainage is evaporated by a few hours' exposure. The mull when wagoned into the factory is generally found to consist of about 40 per cent. peat and 60 per cent. water. This may be considered at first sight as but a poor result to attain; an examination however of the state of the bog in its various stages will show that it is not so, the percentage of water and peat contained in the bog being as follows:—

	WATER.	PEAT.
In its primitive state	90	10
When drained as described	84	16
Upper surface of drained portion	75	25
After some hours of an average dry day	60	40

Hence in any method which commenced by working with the primitive bog, 10 tons of material must be dug out and manufactured for every ton of fuel obtained; and if merely well drained bog be used, 6 tons must be carried for every ton produced. But in the system now in operation it will be seen that only $2\frac{1}{2}$ tons of material are required to make the 1 ton of fuel, all the remaining water having been got rid of before the peat left its primitive position.

Thus far the atmosphere may be relied on to perform the difficult duty of drying; and having attained to the state of not more than 60 per cent. water with 40 per cent. peat, it becomes quite possible to employ artificial heat with economy so as to complete the desiccation. At Derrylea the only artificial heat used is that which

is obtained from the waste steam of the compressing engines, and the smoke and gases from the boiler fires, which would otherwise pass direct up the chimney. These are applied in the drying kilns to heat very extensive surfaces formed of sheet iron, on which is spread a thin layer of peat mull, kept in continual and progressive motion by machinery.

The Drying Kilns are shown in Figs. 6, 7, and 8, Plate 37, and consist of four long chambers, each 500 feet long by 16 feet wide inside, containing an upper and lower floor of thin sheet iron plates extending the entire length, as seen in the transverse section, Fig. 7, and to a larger scale in Fig. 10, Plate 38. The walls are of brick, and the kilns are roofed with tiles, which are found well suited to the purpose, giving through their joints sufficient ventilation, and being themselves good non-conductors of heat. The lower floor EE, Figs. 9 and 10, is composed of $\frac{1}{8}$ inch sheet iron plates, rivetted together, which are carried at a height of 18 inches above the ground by a number of clay pipes FF set on end at about 3 feet distance apart. Underneath this floor is blown the smoke and waste heat from the boiler fires; and instead of the ordinary chimney a large fan is used to urge the fires and force the products of combustion under the floor along the entire length of the kilns.

The upper floor GG, Figs. 9 and 10, is 4 feet above the lower one, and is made double for the purpose of being heated by the waste steam from the engines. It is composed in each kiln of five sheet iron steam chambers, each 500 feet long and 3 feet wide, formed of flat plates at top and dished plates below, as shown enlarged in Figs. 11 and 12, Plate 39, the two plates being rivetted together steam-tight along each side with a continuous space between them $2\frac{3}{4}$ inches deep in the centre. These steam chambers are made of sheet iron $\frac{1}{8}$ inch thick, and are carried on cast iron girders H placed 10 feet apart; and they are arranged so as to overlap one another along the sides, as shown in the full-size section, Fig. 13.

An angle iron rail II, Figs. 9 to 12, runs along each side of both the upper and lower floors, at about 3 inches above their level; and along these rails run the wheels JJ, which carry the endless chains K and the iron rakes L for stirring and carrying forwards

the peat mull. The rakes L are placed at intervals of 4 feet, as shown in Fig. 9; and motion is given to them in the direction indicated by the arrows by means of the hexagonal drums MM, round which the endless chains K pass at each end of the drying kilns, whereby the rakes are kept in continuous motion at the rate of about 100 feet per minute. The peat mull as brought from the bog is fed on to one end of the upper floor, and being gradually dragged along by the rakes to the far end of the kiln it there falls down on to the lower floor, along which it is then brought back by the rakes in the same manner. During this drying process in the kilns almost the whole of the 60 per cent. of water which the mull contained is evaporated, and the mull is then in a fit state for being compressed. By an arrangement of bands and elevators, the dried mull is conveyed into a loft over the engine room, Figs. 6 and 7, whence it descends through spouts direct into the mouths of the two peat presses below.

One of the two Peat Presses is shown in Figs. 14 to 17, Plates 40 to 42; Fig. 14 is a longitudinal section, Fig. 15 a plan, and Figs. 16 and 17 are transverse sections of the press.

The strong cast iron frame NN carries the driving shaft O, which is 7 inches diameter, and has forged on it the eccentric P giving a 7 inch throw. This actuates the horizontal ram R of steel, 4 inches diameter; and the ram moves $3\frac{1}{2}$ inches into and $3\frac{1}{2}$ inches out of the breech of the very strong steel tube S, which is 3 ft. 6 ins. long with 4 inch bore. This tube is made of Bessemer steel, bored cylindrical throughout, and turned down outside in a series of cylindrical steps fitting accurately into the cast iron block T, which is secured to the frame N of the press. The spout U brings down the supply of peat mull from the loft above, and the column of dry mull which it contains rests on the moving ram R as it enters and recedes from the breech of the tube S. At each back stroke of the ram, in the position shown in Fig. 14, a portion of the mull falls down and fills the empty space which has been left from the previous forward stroke of the ram, and this material is pushed by the ram into the tube. After a few strokes of the ram, the peat

driven forwards in the tube becomes so wedged in it that a very powerful resistance is offered by the friction against the sides of the tube: so powerful indeed that each successive charge is consolidated into a separate hard block before the whole mass in the tube yields; and it then moves forwards about $1\frac{1}{8}$ inch, that being the length of one block of the compressed peat formed by the compression of about 4 inches length of peat mull at each stroke.

The outer end or nozzle of the tube S is left entirely open, and the compressed peat is delivered from it in a continuous cylindrical bar, which readily breaks up into the separate discs of $1\frac{1}{8}$ inch thickness each, that are formed one at each stroke of the ram. These discs weigh $\frac{1}{2}$ to $\frac{3}{4}$ lb. each, and about forty of them are formed per minute by as many strokes of the ram. As the tube however is 3 ft. 6 ins. long, each block remains about one minute under pressure, which is an essential feature of the process; and the quality of the compressed peat as fuel is further improved by its being made to pass along an open trough continued from the end of the tube to about 300 feet length, from the machine to the peat store or wagon, Figs. 1 and 8, without rupturing the continuous cylindrical bar in which the peat issues from the machine. At the end of this trough the separate discs of the peat having become by that time loosened fall out successively, one being delivered for each stroke of the press.

As this mode of preparing the peat frees it so completely from moisture, it is natural to expect that its duty as fuel will be greatly improved by the process; and it is accordingly found that the peat thus prepared is capable of performing nearly double the work of average common peat, and from 60 to 66 per cent. of the duty of good coal. It is well adapted for the boilers of stationary engines, and for brewers' work; and has found a ready sale for household purposes, its great cleanliness and freedom from smoke being a strong recommendation. The stowage room required is just the same, weight for weight, as that of coal.

A very good gas is made by using one third of cannel coal and two thirds of this compressed peat; but it is probable that from the

application of the peat to the manufacture of iron the most useful results will yet be derived. This fuel has already been applied in the cupola for casting purposes with complete success; and although it requires peculiar treatment, yet there can be no doubt that, possessing as it does many of the good qualities of charcoal, it will become rapidly adopted for most metallurgical processes wherever it can be obtained.

The PRESIDENT remarked that the subject of the paper was one of great importance to Ireland, on account of the vast extent of peat bogs in the country; and he trusted the attempt now being made to utilise the peat in the manner that had been described would prove practically successful. He enquired what was the cost per ton at which the compressed peat could be delivered in Dublin, and whether any quantity could be produced that was required.

Mr. HODGSON replied that the compressed peat was now delivered on the quay side in Dublin at 10*s.* per ton, and at houses for 11*s.* 6*d.* A very large quantity had already been sold in Dublin, but the works were not yet sufficiently extensive to turn out more than a limited make per week, say about 180 tons.

Mr. W. E. NEWTON enquired whether the peat had been tried for the manufacture of iron, and if so how it had been found to stand the blast.

Mr. HODGSON replied that the peat was not capable of standing the blast in a blast furnace, but it had been employed successfully for melting iron in reverberatory furnaces; it was used for that purpose at the Derrylea Works, and was found to stand very well in the reverberatory furnace with a fan blast.

Mr. W. E. NEWTON thought the importance could not be overrated, to Ireland especially, of the manufacture of peat into such a state that it could be made commercially useful. Various attempts at condensing the peat into solid fuel had been made; but

although to those unacquainted with the nature of the substance its preparation might appear an easy task, it was practically one surrounded by a great many difficulties, as was apparent from the description given in the paper that had been read of the process of manufacture carried out at Derrylea. He was glad to learn however that many of these difficulties had now been overcome in the mode of manufacture described in the paper, and hoped that further endeavours would be made to bring the peat into such a state that it might be profitably used in the manufacture of iron. Thus far the peat had only been compressed, which did not appear to be enough to render it applicable to the manufacture of iron; as for that purpose it required to be converted into the state of charcoal, so as to enable it to stand the blast. As regarded the manufacture of gas from the peat, the principal difficulty arose from the fact of the peat containing so large a quantity of oxygen, in consequence of which the amount of carbonic acid gas generated by the distillation of the peat was too great to be easily eliminated from the carburetted hydrogen produced; and therefore the attempts hitherto made to obtain carburetted hydrogen gas from peat had been unsuccessful. It was possible however he believed to drive off a portion of the oxygen by a preliminary process of slightly charring the peat, so as to allow of the subsequent distillation of the carburetted hydrogen without an excessive quantity of oxygen or carbonic acid; taking care however that the heat employed was not too high, otherwise the peat would be converted into charcoal and some of the valuable volatile products lost. The manufacture of gas from peat, when it could be successfully accomplished, would be attended with considerable advantages, because the peat contained a number of other useful products, such as peat charcoal and peat grease, which was a good lubricator; and these would not only pay for the manufacture of the gas but would yield a sufficient profit in addition.

He had himself paid some attention a few years ago to the question of the manufacture of peat, and found that a very general interest was felt in the subject by landowners throughout the kingdom, particularly in Ireland and Scotland. Many attempts

had already been made to compress peat, and to expel the water from it by pressure; but it appeared to be a peculiarity of this substance that, notwithstanding any amount of pressure that was used, it was not possible to express the water from the peat beyond a certain percentage, which was loose, as it were, amongst the fibres. The only truly efficient plan of getting rid of the water seemed to be that carried out at the works described in the paper, by exposing a very extensive surface of the peat to the atmosphere so as to allow the water to be evaporated. He had seen a plan somewhat similar in principle, though differing in detail, successfully carried out by Mr. Buckland at Creevelea, about 14 miles from Sligo. The bog was first drained as much as possible by trenches cut through it, and then the black watery and greasy peat was taken from the bottom of the bog, and in that state was put into a conical vessel perforated with a number of holes, having a central shaft with a broad-bladed screw and radial arms upon it. This formed a sort of pug mill, and as the shaft turned round, the peat was forced out through the small holes in the form of long strings like vermicelli, and in this finely divided state a very large quantity of the water became readily and quickly evaporated by the air. After a further drying by passing through a drying chamber the peat was finally consolidated in a press; but it had not been found necessary to employ any considerable amount of pressure for the purpose: a handful of the material could in fact be squeezed by hand into a sufficiently solid form for all practical purposes to which it was intended to be applied. The peat might therefore be said to be simply moulded into shape rather than compressed; and when the moulded blocks had been further dried in a drying chamber and properly charred, it was found they would bear almost any amount of blast to which they might be subjected in a blast furnace. This process of peat manufacture was already being carried out at Mr. Danchell's ironworks at Horwich in Lancashire, and also at Creevelea, to a sufficient extent to prove its utility; and he exhibited a piece of pig iron produced at Creevelea, which he considered a very good sample of iron. It was made from iron ore found in that neighbourhood, and smelted in the blast furnace

with peat manufactured according to this process, and was called Irish charcoal iron. The cost of production was estimated at about £1 13*s.* 6*d.* per ton of pig at the works, exclusive of wear and tear and interest upon capital; and the cost of bar iron made with peat charcoal from the same pig iron was estimated at about £4 11*s.* per ton at the works, or £4 16*s.* per ton delivered on board at Sligo, 14 miles distance. The cost of the peat charcoal at the works was about 6*s.* per ton, and the quantity required in the blast furnace was about 30 cwts. per ton of pig iron made, and in the puddling furnaces about 35 cwts. per ton of bar iron produced. The steam for the blast engine and forge engine was raised by the combustion of the waste peat left in the process of manufacture.

Mr. HODGSON observed that the process just described for peat manufacture confirmed his own experience as to the chief difficulty to be contended with, which was to get rid of the water contained in the peat; but he thought the plan proposed for the purpose was open to much objection. For by taking the peat wet from the bottom of the bog, 8 or 9 tons of water had to be handled for every ton of peat afterwards made; and the solidification of the peat into blocks, after its fine subdivision by the ingenious process that had been mentioned, depended upon the evaporation of this large quantity of water by artificial means. Artificial drying however could only be produced either by the direct application of heat, as at Derrylea, or by an air blast, which must be generated by steam power and would therefore involve consumption of fuel. Supposing the wet peat from the bog to contain only 8 tons of water per ton of peat, then there must be at least 7 tons of water dried out of it before it could be consolidated; and in order to derive any profit from the manufacture, it would be necessary that 1 ton of peat should not merely be capable of being economically applied to dry out 7 tons of water, but that it should also leave a sufficient surplus of fuel for sale, which was evidently altogether impracticable. For it was not bad duty for a Cornish boiler to evaporate 7 tons of water with 1 ton of coal of the ordinary kind; and peat was not so good a fuel as coal, and the mode of its application to drying purposes could not be so advantageous as when used under a boiler.

In the manufacture of peat at Derrylea the bog was first drained as much as possible, which would of course be done in any case, whatever process of manufacture were adopted. But instead of taking the wet peat from the bottom of the bog, a thin portion of the surface only was operated upon, which was always the driest; and by repeatedly harrowing this over, the peat was so far dried by the exposure to the air that it was obtained from the bog with only $1\frac{1}{2}$ ton of water per ton of peat, making only $2\frac{1}{2}$ tons total weight to be handled, the rest of the water having been evaporated out by the atmosphere, before any artificial drying was attempted. Until this advantage was gained of obtaining the peat dried to that extent by natural means, he did not think there was any use in attempting to dry the peat artificially; but when the peat was already brought by natural drying to such a state that it contained only $1\frac{1}{2}$ ton of water per ton of peat, then it was practicable, with 1 ton of peat to expend, both to get rid of this remaining $1\frac{1}{2}$ ton of water and to have still a large proportion of the peat left for carrying on the manufacture and for sale. This was what had been found to be the case in the actual working of the system at Derrylea, and the plan there carried out was the only one at present he believed that had stood the test of actual commercial manufacture, the other process that had been referred to not having yet been carried so far as the actual manufacture of the peat for sale.

The PRESIDENT remarked that in reference to the use of peat for the manufacture of iron he remembered a small quantity of iron being manufactured with peat only at the Muirkirk Iron Works in Ayrshire about twenty-five years ago: it was made for the axles of carriages, and proved far better than any other iron manufactured at that time either in England or Sweden.

Mr. I. SMITH enquired whether the peat had been tried for the manufacture of lighting gas, and what was found to be the illuminating power of gas made from peat alone. He understood that in some parts of Germany, where the only fuel to be had was wood, it had been endeavoured to obtain from wood a lighting gas; but this being nearly all hydrogen was of a very poor illuminating quality. A plan had however been devised by Liebig for increasing

its illuminating power by passing it a second time through the retorts; for it appeared that the heat which was sufficient to distil the lighting gas in the first instance from the wood was not enough to decompose the carbonaceous parts of the wood; but by first distilling off the gas at this moderate temperature, and afterwards increasing the heat to such an extent as to get the carbonaceous portion of the wood decomposed, the gas on being then passed a second time through the retorts took up sufficient carbon to give it a high illuminating power. By this means a very beautiful lighting gas was produced, almost equal to that obtained from cannel coal, and without any of the ill effects of sulphur; and several towns in Germany were now lighted with gas produced in this manner from wood. As peat had the same advantage of freedom from sulphur, he thought it would be a great benefit if it could be made to yield such a gas for illuminating purposes.

Mr. HODGSON replied that they had put up a small gas apparatus at Derrylea, which was employed successfully for lighting the works. A mixture was used of two thirds peat and one third cannel coal, and the gas produced from this mixture compared advantageously in illuminating power with the ordinary coal gas made in Dublin, while the quantity made exceeded he believed that obtained from coal alone. He had heard of the process that had been mentioned for increasing the illuminating power of gas obtained from wood, and hoped to try it shortly with the peat; hitherto the main object had been to turn out a sufficient quantity of manufactured peat for commercial purposes, and having now succeeded in doing this, he hoped further to perfect the various uses to which the peat could be applied.

The PRESIDENT enquired whether the sheet iron floors of the drying chambers had been found to become corroded by the constant passage of the peat over them.

Mr. HODGSON replied that the drying chambers had been in use continuously ever since their erection fifteen months ago, and the floors did not show any signs of wear or corrosion. He had not seen the inside of them since they were put up, but the outside was

as smooth and clean as possible, and there were no signs of any corrosion having occurred; the thickness of the plates was only 1-8th inch.

Mr. W. E. NEWTON enquired how long the peat was in passing through the drying chamber.

Mr. HODGSON believed the time occupied by each portion of the peat in passing through the drying chamber to the extremity and back again was about from 1 to 1½ hour.

Mr. H. W. HARMAN enquired whether the form in which the peat was now exhibited of circular discs was the form in which it was supplied for commercial purposes; and what space the compressed peat occupied per ton.

Mr. HODGSON replied that the peat was supplied in the form of discs, like the specimen exhibited, 4 inches diameter and rather more than 1 inch thick, and 1 ton of the peat in that form occupied about 44 cubic feet in ordinary stowage without packing. It was delivered in Dublin in the ordinary coal sacks used for delivering coal; the sacks were filled rather fuller with the peat than with coal, and were reckoned at sixteen sacks per ton.

Mr. J. FERNIE suggested that it would be preferable if the form of the peat discs were made hexagonal or square, so as to allow of packing them without loss of space between.

Mr. HODGSON said that if the peat discs were made hexagonal or square it would be necessary to pack them by hand in order to obtain the benefit of saving the space between; and it would then be found practically that the expense of packing would counterbalance the advantage of the space saved.

Mr. J. KENNAN enquired whether any attempt had been made to harrow the surface of the bog by employing wire ropes to draw the harrows in a similar manner to the plans adopted for working agricultural implements, instead of using the long girder frame travelling over the bog and having the harrows attached to it, as described in the paper; or whether the use of wire ropes was considered to be attended with any practical disadvantage for the present purpose. He asked also whether the final form of discs, in which the peat was supplied, was produced by the

compression alone, or whether there was any further drying process subsequent to the compression, and what percentage of water remained in the peat after its manufacture into the discs supplied for sale; and also what had been found to be the durability of the steel cylinder in which the peat was compressed.

Mr. HODGSON replied that he had consulted the late Mr. Fowler respecting the application of ropes for working the harrows over the bog, but that plan had never been tried for the purpose, as it was found it would be so expensive; and the present mode of working with the long girder was so much more simple and appeared so much better adapted to the circumstances of the case that it was adopted instead, and had proved perfectly successful. With regard to the drying of the peat, there was not any subsequent drying after compression, and the dried mull from the drying chamber that was supplied to the peat press was as dry as it was required for commercial purposes. He did not know with certainty what average quantity of water then remained in the peat, but it was not more than 6 or 7 per cent. and frequently much less.

In reference to the durability of the steel tube in which the peat was compressed, the first portion of the tube where the disc of peat was formed by the pressure of the ram became worn away 1-8th inch all round in three weeks' working. It was then taken out and a spare tube substituted, while the first tube was bored out at the mouth and a steel bush put in; the cost of doing this amounted to about 15*s.* or 16*s.*, and it required to be done every three weeks. The entire tube required to be bored out and bushed throughout its whole length about once every four months. The same outside tubes were still at work that had been employed at starting two years ago, although they had been repeatedly bushed in working. The outer end of the tube was prolonged and turned down to 3-8ths inch thickness, as shown in the drawing (Figs. 18 and 19, Plate 42), and then split up with four saw cuts; and a tightening clamp was placed upon it with screws for tightening it up, so that the tube could be slightly contracted towards that end. The peat when it got past the solid part

of the tube had a tendency to expand slightly, and this expansion was counteracted and a slightly increased pressure put upon the peat by tightening the clamp upon the tube; by this means also the resistance offered to the ram of the press was regulated to a certain extent. Without the power of increasing or diminishing the friction in the tube in this manner, as might be required, it might occasionally happen from variations in the state of the peat that there was too much or too little pressure upon the peat in the formation of the discs. If the mull were of rather a light quality, and the clamp were not on, it sometimes happened that the column of peat would slip in the tube, so that the pressure against the ram ceased; but by then tightening up the clamp the resistance was increased until the pressure was brought up again to the point necessary for the proper formation of the discs.

The PRESIDENT enquired whether the ram of the press was found to wear as rapidly as the tube, and how it was repaired when worn.

Mr. HODGSON replied that the end of the ram became worn a little all round the edge in about the same time that the mouth of the tube required to be rebushed; and the face of the ram was then "jumped up" by heating it and hammering it up to the full size of face, after which it was turned and faced again in the lathe.

Mr. F. W. WEBB suggested that the bushes of the tube and the face of the ram might be casehardened, in order to render them more durable.

Mr. HODGSON said the bushes in the tube were all casehardened, but he had not yet tried casehardening the ram also.

Mr. J. RAMSBOTTOM enquired whether chilled cast iron had been tried for the bushes of the tubes; he thought that would be a better and more durable material for the purpose than steel.

Mr. HODGSON said he had not tried chilled cast iron for the bushes, but he had thought of making the whole length of the tube of chilled cast iron, by casting it upon a hollow mandril filled with cold water.

Mr. J. RAMSBOTTOM observed that there would be some objection to making the long tube itself of chilled cast iron, as it would then

have to be ground out afterwards, which would be a troublesome operation in a tube of that length; unless indeed it were not chilled so hard as to prevent its being bored out in the usual manner.

With regard to the mode of finally drying the peat mull in the drying chambers, he thought there must be a considerable amount of oxidation on the steam side of the plates composing the hollow floors, and being only 1-8th inch thick they could scarcely be expected to prove very durable; and he enquired whether the use of hot air had been tried for drying the peat, to avoid having to make use of steam for the purpose. He suggested also that by the use of hot air the arrangement of travelling scrapers for carrying the peat along the floor of the chamber might be dispensed with, by carrying the peat upon an endless belt travelling in the opposite direction to the current of heated air.

Mr. HODGSON replied that he had tried drying the peat by blowing a current of hot air through it, but there were practical difficulties in the way of carrying out that plan, and the air blew away a great deal of the finer portion of the peat powder, causing a serious waste; and that mode of drying had not been found to answer so well as the exposure of the peat in a thin layer with a large extent of surface, as was now done in the drying chambers with the hollow floors heated by steam. He did not think it would be advisable to dispense with the scrapers now employed for scraping the peat along the floors of the drying chambers, because then the peat would not be stirred at all; and if carried upon an endless band it would go forwards in the exact position in which it fell upon the band, and would not receive that continuous stirring which was so essential a feature of the present arrangement, exposing constantly a fresh surface to be dried by the heat.

The PRESIDENT enquired what extent of bog was now being worked over with the harrows under the system described in the paper, and whether the working had been confined to one part of the bog or had been carried on in different places. He asked also whether the bog was found to sink much after being drained.

Mr. HODGSON said the working had been confined hitherto to one portion of the bog, of about twelve acres, which was not yet

half exhausted after two years working. After draining the bog in the first instance it sank fully one third of its depth.

Mr. J. WHITLEY enquired whether any use had been made of the ashes after burning the peat; he thought they would be found very beneficial in smelting iron, by mixing them with the fuel in the blast furnace.

Mr. HODGSON replied that he had kept the ashes made at the works from the peat burnt in the furnaces, thinking they might perhaps be sold at a low price for agricultural purposes; but he had not supposed that any application could be made of them in connection with smelting iron.

The PRESIDENT proposed a vote of thanks to Mr. Hodgson for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by free train, by the kindness of the Dublin and Wicklow Railway Company, to Carrickmines, to visit the Lead Smelting Works of the Mining Company of Ireland at Ballycorus, where they were shown the various operations connected with the smelting of the lead ore and the separation of the silver, the manufacture of sheet lead, lead pipes, and red lead, the refining of the silver extracted from the lead, and the manufacture of shot at the shot tower. The Members were hospitably entertained at the works by the directors and officers of the Mining Company; and afterwards returned to Dublin by free train.

In the evening the Members were invited by the Local Committee to a Conversazione at the International Exhibition, which was specially lighted up for the occasion. In the machinery department, the portable steam rivetter described at the meeting was shown in operation, rivetting plates of $\frac{1}{2}$ inch thickness with $\frac{7}{8}$ inch rivets.

The Adjourned Meeting of the Members was held in the Examination Hall, Trinity College, Dublin, on Wednesday, 2nd August, 1865; ROBERT NAPIER, Esq., President, in the Chair.

The following paper, by Mr. Thomas Grubb, of Dublin, Engineer to the Bank of Ireland, communicated through the President, was read:—

DESCRIPTION OF THE BANK-NOTE PRINTING MACHINE AT THE BANK OF IRELAND.

By Mr. THOMAS GRUBB, of Dublin.

In the manufacture of Bank Notes, the printing has usually been accomplished from engraved plates, as affording a better protection against fraudulent imitation; but the slowness and consequent increased expense of this manner of printing, as compared with ordinary type or surface work, have led in some instances to the abandonment of the finer and better protective process. Improvements of a minor character have been made from time to time in the presses used for printing from engraved plates; and the note-printing press of the late Mr. John Oldham, long in use in the Bank of Ireland and subsequently in the Bank of England, may be mentioned as perhaps the best example. But any attempts to abridge the labour and time of the operation by inking the engraved plates by means of machinery appear to have failed entirely, previous to the construction by the writer of the machine to be described in the present paper.

The process of printing from an engraved plate may be considered as divided into three separate portions, namely: first, the inking of the plate; second, the wiping of the plate; and third, the taking of the impression, including laying and removing the paper. All these are usually performed by hand, excepting the actual taking of the impression by the press; and each of the three operations occupies about the same time in performance, in consequence of which all three operations are arranged to be proceeded with simultaneously in the machine about to be described.

The Bank-Note Printing Machine is shown in Figs. 1 and 2, Plates 43 and 44; Fig. 1 is a side elevation, and Fig. 2 a vertical section taken at right angles to Fig. 1.

The machine consists of a horizontal polygonal cylinder A, Figs. 1 and 2, of twenty sides, on ten of which are held the ten engraved plates from which the notes are to be printed. These ten engraved plates are held in position in dovetails formed by ten plain plates screwed upon the ten intermediate sides of the polygon. The plates and polygon are maintained at the proper temperature for working by steam admitted inside the hollow polygon through the back bearing B, Fig. 2.

At the ordinary rate of working, each impression occupies 10 seconds; and the polygon is held stationary during 8 seconds of the time, and during the remaining 2 seconds it is turned round through 1-10th of a revolution, in the direction shown by the arrow in Fig. 1, so as to bring the next engraved plate to the top for being printed from. During the 8 seconds that the polygon is stationary, the undermost plate at C is inked by the machine, the uppermost plate at D is printed from, and the plate at E has the wiping of its surface completed. The machine requires two attendants, one standing in the box F, who lays the paper, removes it after being printed, and observes that the work is proceeding satisfactorily; while the other gives the final wiping by hand to the surface of each plate as it comes into the position E, Fig. 1. The greater portion of the superfluous ink is wiped off by the machine, thereby lessening the labour of the final wiping by hand; this is done by means of the wiping roller G, on which is wound a length of cotton cloth. This wiping roller is stationary while the polygon is at rest; but on the polygon beginning to move, the roller presses against the surface of the previously inked plate, and by turning in the opposite direction wipes off the superfluous ink. When the surface of this roller becomes surcharged with ink, a length of the cotton cloth upon it equal to one round is torn off. By the revolution of the polygon therefore each plate on arriving at the bottom at C is inked, and as it proceeds upwards is first partially wiped by the machine at G, and afterwards finally wiped by hand

at E, and on arriving at the top is printed from by the printing roller D.

Several special contrivances are required for producing the respective actions of the machine, the principal of which are the apparatus for locking and turning the polygon, and for the motions of the printing roller, and the inking apparatus.

At each printing the polygon is subjected to a heavy strain by the vertical pressure of the printing roller D, Fig. 1, tending to turn it first in one direction and then in the opposite direction alternately, as the printing roller passes over from one side of the centre to the other; it therefore requires to be very firmly locked during the time that it has to be held stationary for printing. This is effected by the locking lever H, which being lowered by its cam inserts the steel tooth I into one of the ten spaces round the circumference of the polygon. The turning of the polygon through one tenth of a revolution between each printing is accomplished by the levers and cams K K and L L; one of these levers K alternately withdraws and protrudes the tooth J, while the other L moves the carrier box M through the required arc. The action of the levers H and K is so arranged that as the tooth of the locking lever is withdrawn that of the turning lever enters the toothed circular plate N and *vice versâ*. The polygon is thus sure to be duly acted upon, and always under restraint, thereby ensuring against risk of accident, which might occur if ordinary means were employed for turning the polygon.

For working the printing roller D, Figs. 1 and 2, the ordinary method of causing it to roll up an inclined plane into contact with the plate was inadmissible in the present machine, and the following arrangement has been adopted for the purpose instead. The roller is first caused to descend vertically at the proper time and with a sufficient pressure upon the plate, on which the paper to be printed is previously laid: next the roller is carried horizontally over the surface of the plate, to produce the impression; and thirdly it is raised from the plate and withdrawn to its first position. The motion of the centre of the roller is therefore as shown by the dotted

line P Q R in Fig. 3, Plate 45; and this motion is produced in the following manner. The vertical descending movement from P to Q is effected by the long trussed rod O and its double cam, acting on the bell-crank S and toggle-lever joint T. The horizontal traverse from Q to R is produced by the printing cams and their levers U acting upon the sectors V, Figs. 2 and 3. These sectors roll against inverted straight edges W, and the bearings of the printing roller D being concentric with the arcs of the sectors V, the roller is traversed horizontally over the engraved plate. The curved motion from R to P, in withdrawing the printing roller and returning it to its original position, is produced by the joint action of the two sets of cams. The blocks W, against which the sectors V roll, slide vertically in grooves in the side frames of the machine; the underside of these blocks is faced with a flat surface of hardened steel, against which rolls the upper segmental surface of the sectors, which is also made of hardened steel. These steel bearing surfaces are retained in contact by the spiral springs X, Fig. 2, which carry the weight of the sectors, the printing roller, and the levers U. The sectors are prevented from slipping in rolling against the blocks W, by means of bridle levers, which admit of motion in other directions, but prevent slipping. An endless sheet of flannel Y passes round the printing roller D and over the guide rollers Z above, travelling in the direction shown by the arrows in Fig. 3; the upper rollers Z are carried by the sectors V and slide blocks W.

The inking of the engraved plates is performed by the inking roller C, Figs. 1 and 2. Upon the capability of the machine to ink the engraved plates effectively depends its usefulness; and herein lay the main difficulty, and the reason of the failure of previous attempts at improvement. The difficulty was much enhanced by the circumstance that, in using the ink applicable to engraved plates, a portion of it becomes thickened and unfit for immediate use. In the ordinary hand-inking this thickened ink collects in a ring on that part of the dabber which barely comes into contact with the plate during the inking; and this requires to

be removed occasionally from the dabber by a knife or scraper, otherwise by its mixing with the fresher ink the quality of the work would be injured. In experiments made preliminary to constructing the present machine, a cylindrical roller was used for inking the plates by hand, and was supplied with ink from a perforated surface, through which the ink was caused to exude; and it was found that the thickened ink, technically termed "gatherings," adhered at first to the perforated surface between the perforations, and afterwards when the film had arrived at a certain thickness it was transferred bodily to the surface of the inking roller. These experiments led to the adoption of the following inking apparatus.

The short cylinder P, Figs. 1 and 2, containing the supply of ink, is fitted with a piston, the rod of which is a screw that projects below the cylinder, as shown in Fig. 2. The upper end of the cylinder expands into a horizontal rectangular tray, rather larger in size than the plate to be inked; and this tray is covered with a flat plate of steel, perforated with a number of small holes. The piston is slowly raised by the screwed piston-rod and the bevil wheels Q and ratchet wheel R. In order to charge the cylinder with ink the piston is lowered and the perforated top plate removed for filling in the ink; and on replacing the top the piston is raised until the ink exudes through the perforations in the top plate, the lowering and raising of the piston being effected by hand by a winch upon the spindle of the ratchet wheel R. The supply of ink during the working of the machine is kept up by the lever T from the cam shaft, Fig. 1, acting on the ratchet wheel R, a small but sufficient quantity of ink being in this way forced up through the perforated surface for every plate inked by the inking roller C.

The inking roller C, shown enlarged in Figs. 4 to 6, Plate 46, is formed of a number of discs of woollen cloth, screwed up tightly together upon a spindle and finished in the lathe. It is worked to and fro continually without intermission by the rack and sector B. This rack slides on a cylindrical rod D, which allows the frame E carrying the roller to be raised and lowered sufficiently for causing the inking roller either to apply ink to the engraved plate on the polygon A above, as shown in Figs. 4 and 5, or to descend and roll

on the inking table P below, for obtaining a fresh supply of ink, as shown in Fig. 6. The roller is held up for inking the polygon by the weighted lever G, having an adjustable weight; and on the pressure of this weight being removed at the proper moment by a cam, the roller C drops and rolls upon the inking table P with its own weight and that of the frame E, as shown in Fig. 6. It thus takes up a fresh supply of ink, while the polygon is turned through one tenth of a revolution so as to bring the next engraved plate round into position, ready to be inked when the inking roller is raised again by the lever G.

As the ink is transferred from the perforated inking table P to the inking roller C in a series of dots through the holes in the inking table, the engraved plates would be inked in a similar and therefore imperfect manner; but this is prevented by the application of the two small distributing rollers I I, which are pressed in contact with the inking roller by springs. One of these distributing rollers simply revolves in contact with the inking roller; but the other has one of its bearings a screw, which gives it an end traversing motion in addition to the rotary motion; and thus the ink coming to the roller in dots is equalised over its entire surface, and the inking of the engraved plates is rendered uniform all over.

The occasional removal of the thickened ink from the surface of the inking table P is provided for by the arrangement shown in Fig. 7, Plate 47. The ink scraper J is shown in the position when out of action, and H is the lever and M the connecting rod for communicating the required motion to it from the cam N. On the scraper beginning to move across the inking table P from the position shown at J in the drawing, a small cam at each end causes it to rise and so to pass clear over the table without scraping; while in the return motion the scraper descends into contact with the table, and pushes before it the thickened ink, which falls into a trough placed to receive it.

If the scraping were to be performed once for every impression printed, then it would only be required to allow the cam roller at the end of the lever H to remain continually in the groove of the

cam N. But as it is required that the scraping should be performed only occasionally, or once for every 36 impressions or revolutions of the cam shaft, the following arrangement is adopted. At O is a latch, which so long as it is not raised holds the connecting rod M pushed outwards laterally, so that the cam roller is out of the cam groove N. The ratchet wheel Q has 72 teeth, and is carried forwards one tooth for every impression by the paul R, which is actuated by the cam shown by the dotted line. Attached to the ratchet wheel is a disc S, having only two notches TT in its circumference; and U is a rocking frame, rocking on a pin at its lower end, and having on the upper part a projecting finger, which is caused by the weight W to press continually against the edge of the disc S. V is a bolt, worked up and down at each revolution of the cam shaft by the same lever and cam that work the paul R of the ratchet wheel. The upper end of this bolt slides in the rocking frame U; and so long as the finger is on the edge of the disc S, the bolt V rises and falls just clear of the latch O, as shown in the drawing, so that it produces no action.

But once for every 36 impressions of the machine the finger of the rocking frame U enters one of the notches T in the disc, and the rocking frame falling forwards tilts the bolt V into the position indicated by the dotted line, when the next rising of the bolt lifts the latch O, as shown by the dotted line. The cam roller is now thrown into the cam groove N by the lateral pressure of the spring lever H, and the scraping of the inking table P is performed once by the revolution of the cam N. At the end of the revolution the cam roller is thrown out of the cam groove N by the inclined stop X at the end of the groove, and is instantly held out by the dropping of the latch O; and before the bolt V again rises, the ratchet wheel Q has been turned forwards one tooth, so that the finger of the rocking frame U is again out of the notch T, and therefore the bolt V rises clear of the latch O and ceases to lift it for the next 36 impressions.

In the planning and also in the construction of the present machine and other similar ones, the writer has derived much advantage from

the use of Babbage's system of mechanical notation by means of a chart. In the construction of automatic machines, where there are of necessity interrupted or occasional movements, there is frequently much improvement to be effected upon the original foundation; and this is usually accomplished by expensive mechanical alterations. But the use of a chart admits of its being done much more readily and efficiently, and this system also provides by inspection the data for the required curves of the several cams, and for keying the cams at once upon their shafts in the exact positions required, without recourse to tentative trials.

In Fig. 8, Plate 48, is shown the diagram of the principal cam motions in the bank-note printing machine, as used in the construction of the machine, showing the respective motions during one revolution of the cam shaft.

The PRESIDENT thought the machine described in the paper was very beautifully contrived for the purpose; he had had an opportunity of seeing it at work, and had been much struck with the simplicity of its construction, and the accuracy of its working. He enquired what was found to be the durability of the wearing parts, and whether any of them had required to be replaced.

Mr. GRUBB replied that there were two of the machines described in the paper in use at the Bank of Ireland for printing the bank notes, one of which had been in constant use for about fourteen years with scarcely any repairs, and was still working quite as well as when first started. The only renewal had been in the case of the pressing cam upon the main driving shaft, which gave the heavy pressure upon the printing roller for working off the impression; this cam had required to be renewed once, after being in constant work for about fourteen years. The only other defect had been in the

original casting of the polygons for both the machines, in consequence of the unequal contraction of the metal in cooling, which caused one end to give way in each polygon by separating from the circumference of the polygon, showing that the metal had been subjected to a considerable strain in the cooling of the casting. This difficulty was obviated in each case by cutting out the end of the polygon and bolting on a new end, to avoid having to re-cast the polygons; this had proved completely satisfactory, and the polygons had worked ever since with entire success.

The PRESIDENT enquired what was the amount of pressure upon the printing roller when in operation.

Mr. GRUBB said the total pressure upon the printing roller was about 3 tons, which obliged considerable force to be exerted by its cam. A very heavy pressure was required, in order to make sure of producing a good impression in all parts of the note that was being printed.

The PRESIDENT enquired whether the engraved plates were found to wear out faster when printed by the machine than in ordinary hand printing.

Mr. GRUBB had not found any difference in the wear of the plates in printing by the machine. The principal source of wear was the use of the whiting employed for the final cleansing and polishing of the engraved plates by hand immediately before the impression was taken; for though the whiting was employed in the state of a soft fine powder, it had a slight cutting action which gradually wore away the engraved plates; and this polishing process was the same in either case, whether the printing were done by hand or by the machine.

The PRESIDENT enquired how the plates were engraved in the first instance, and what means there was of renewing the engraving when it became faint in any places in consequence of the wear.

Mr. GRUBB explained that the separate subjects or designs forming the complete bank note were engraved by hand in the first instance on separate steel blocks, which were afterwards hardened and were preserved as the permanent patterns, not to be printed from. The engravings were then transferred in relief to the surfaces

of soft steel rollers, by rolling these over the pattern blocks under a heavy pressure; and the rollers being afterwards hardened were used as dies to impress the engraving upon the printing plates, in a similar manner to that long employed for engraving the copper cylinders used in calico printing, but requiring a far greater amount of accuracy in the present instance. The engraved plates for printing the bank notes were made of soft steel, and were never hardened after being engraved, because being of large size, 20 inches long by 6 inches wide, they would almost certainly not retain their flatness in hardening. Moreover when worn in printing the soft plates were easily repaired again by means of a special arrangement that he had designed for the purpose, which enabled the rollers to be applied again to the plates with perfect accuracy for renewing the impression. In first impressing the plate with the master roller or die, the plate was fixed upon the table of a strong pressing machine, capable of exerting a pressure up to 5 tons, regulated as required by means of a weighted lever; and the position of two register points in the plate being accurately noted by means of a micrometer microscope was registered in a book kept for the purpose; the master roller was then passed over the plate by the machine under the heavy pressure, being very steadily guided by a special parallel-motion arrangement, with pressing sectors similar in principle to those of the note-printing machine described in the paper. The table was provided with complete adjustments of very great delicacy, and the pressure of the engraving roller upon the plate was not produced by the roller descending upon the plate, but by the table being raised up to the roller: the table being of considerable weight was balanced, so that it was moved vertically with a force of a few pounds; and it was provided with two separate lever arrangements, one for light and the other for heavy pressures, whereby any pressure from a few pounds up to the 5 tons could be put upon the plate. For renewing the impression on any subsequent occasion, the plate was again fixed upon the table in exactly the same position as before, by means of the micrometer microscope and the register of its position; and the roller was then passed over it again, to deepen those parts of the impression

which had become worn in printing. The accuracy with which the renewal was effected by this means was so perfect that the finest lines in the engraving were preserved without becoming perceptibly coarser even after the plate had undergone renewal many times; and the most delicate engravings on the plates when worn by the process of printing were restored as often as required with the greatest certainty and facility. By a delicate adjustment in the bed of the table, the plate could be slightly tilted, transversely to the direction of motion of the roller, so as to give the means of bringing up the impression on any special portion of the plate by increasing the pressure upon that part. This tilting motion was effected by the bed being made with a convex cylindrical segment lying within a concave one, the plate to be engraved being in the centre of motion; and the movements for adjustment were effected by screws, which gave facility for adjustment to the thousandth of an inch.

Mr. R. MALLET remarked that scarcely sufficient prominence had been given in the paper just read to the very important improvements that had been effected by the writer himself in the invention of the beautiful bank-note printing machinery now employed in the Bank of Ireland, which could not be fully appreciated without a reference to the imperfect method previously in use for printing bank notes.

Prior to about the year 1820 all bank-note printing was performed by hand labour alone, by copperplate printers, in the same way as the printing of fine art engravings. About that time the elder Mr. John Oldham, who had been a working calico printer, devised machinery for performing the printing of bank notes by mechanical means, which was constructed by Mr. John Mallet of Dublin, and employed for several years at the banks both of Ireland and of England. Steel engraving being then unknown, the impressions were taken from copper plates, inked and cleaned by hand in the old way, and heated on flat steam tables on which they lay during the process. The plate was then laid upon the table of the printing press, which consisted of a pair of horizontal rollers, one above the other, between which the table carrying the plate was

passed under a heavy pressure. The table was made of gunmetal in two pieces, each of a flat wedge shape, sliding upon each other with much accuracy; so that the top and bottom surfaces of the table always remained parallel to each other, whilst the total thickness was increased or diminished as desired by sliding the wedges over each other. When the copper plate was laid upon the table, the under wedge was slided home, bringing the plate into contact with the top roller; and it was then passed through under severe pressure, taking off an impression upon the sheet of paper placed upon the plate. The idea was thus to print "skin to skin" as it was called, relying upon the accuracy of all parts of the machine being sufficient to produce a good impression without the intervention of any elastic medium, the only elasticity being that of the thin sheet of bank note paper itself. This was ultimately found to be impracticable, and some elastic material such as felt was afterwards used in either one or both of the pressing rollers. To the end of Mr. Oldham's career however, and that of his son, very much of the work of printing the notes was performed by hand; in fact the use of machinery was confined to rolling off the impressions from the plates, which were inked and wiped by hand, and transferred by hand to the printing machine. Even the numbering machines he believed were worked entirely by hand, and required changing by hand after a certain number of figures had been passed.

Upon Mr. Grubb's appointment as engineer to the Bank of Ireland in 1842 he departed at once from all existing plans for bank-note printing, and produced the automatic machine described in the paper; and nothing could be more striking than the perfection of its action, and the foresight with which every part of the process of printing the notes had been provided for. The machine presented one of the most beautiful combinations of cam work that was to be met with, enabling it to perform with strict accuracy very complex and peculiar movements, involving both very severe pressure and extreme delicacy. The numbering machines also had been greatly improved by Mr. Grubb, increased in their numerical range, made self-inking, and rendered completely automatic.

The PRESIDENT moved a vote of thanks to Mr. Grubb for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A ROCK BORING MACHINE.

By Mr. GEORGE LOW, of Dublin.

In driving a tunnel or quarrying in hard rock, the only method whereby the rock can be worked is by blasting; and the Rock Boring Machine forming the subject of the present paper has been constructed for the purpose of boring the blasting holes, with a view to facilitate and expedite the work by superseding the very slow and laborious mode of performing this operation by hand. The machine is driven by compressed air, and works a boring tool or jumper for boring the holes; and the boring tool works in a direct line with a self-acting reciprocating motion at a very high velocity, and is continuously turned round during its working, being made to rotate slightly between each blow.

The boring tool is fixed direct upon the end of the piston rod of a working cylinder; and this working cylinder moves within another exterior cylinder, in which it is made to rotate for the purpose of giving the rotating motion to the tool. The working cylinder has also a longitudinal forward motion within the exterior cylinder for giving the advancing feed to the tool, the working cylinder being propelled forwards by the compressed air that works the tool, thereby dispensing with the necessity for employing propelling gear, which is liable to break or get out of order and is subject to rapid wear. The exterior cylinder is carried by a spherical trunnion in a moveable radial arm or jib mounted on a travelling carriage, which gives the means of adjusting the boring tool to any desired direction and position, so that the holes may be bored in the most suitable directions according to the strata of the rock for the blasting to take the best effect in breaking up the rock.

This Rock Boring Machine, which is the invention of the writer, is shown in Figs. 1 to 11, Plates 49 to 53. Figs. 1 to 5 are sectional plans and longitudinal sections, showing the boring tool and working cylinder in different positions during the working of the machine; and Figs. 6 to 11 are transverse sections at successive points.

The machine is only 4 ft. 6 ins. total length, being made as short as possible in order that it may be moved in any direction in the tunnel, so as to enable it to be set to bore at any angle and in any position and direction that may be desired. The working cylinder A, Fig. 3, constructed of brass, is placed inside an exterior cylinder B of cast iron, which is fitted with a spherical trunnion C to support it in the radial jib or arm of the travelling carriage, as shown in Figs. 21 and 22, Plate 55. The inner cylinder A is free to move longitudinally within the exterior cylinder from end to end as it advances during the process of boring, as shown in Figs. 3 and 5; and it is also free to rotate within the outer cylinder, for giving the rotating motion to the boring tool D. The back end of the working cylinder A is packed with a cupped leather, shown black in Fig. 5, so as to be air-tight when moving within the exterior cylinder B. The front end of the working cylinder A fits into a wrought iron crosshead E, in which it is free to revolve; this crosshead is bored out on each side to slide upon the two screwed guide bars F F, which are bolted to the exterior cylinder B, Figs. 5, 9, and 10, and are carried forwards to the end bearing G of the machine. The guide bars F have a double thread of $1\frac{1}{2}$ inch pitch chased upon them from end to end, but the thread is planed off on the inner side of each screw down to the body of the guide bar, for the purpose of obtaining greater compactness in the construction of the machine, as seen in the transverse sections, Figs. 9, 10, and 11.

At the back end of the working cylinder A is the air valve N, Figs. 5 to 7, which is a circular disc valve with six inlet ports and six exhaust ports, as seen in Figs. 6 and 7. This valve is turned by a double spiral cam O, which is carried forwards into the end of the piston and piston rod K, and is acted upon by the four rollers P P, Figs. 5 and 8, bearing on both sides of the spiral wings of the cam.

The spiral wings are so sloped that as the piston moves backwards and forwards the cam is gently turned or twisted, carrying with it the air valve N fixed upon the spindle of the cam. The slopes of the cam are so arranged that the valve N opens the inlet ports for admitting the compressed air to act upon the large area of the piston, in order to make the forward stroke of the tool; and the valve is then turned so as to allow the air to exhaust again after the piston has struck the blow. The return stroke of the piston is produced by a constant pressure of the compressed air upon the small annular area of the front of the piston, the pressure for this purpose being maintained through the two ports shown in Figs. 5 to 9, which are always open. The exhaust air is discharged at the front end of the exterior cylinder B, being carried along grooves in the circumference of the working cylinder A, as seen in the plan Fig. 3, and the transverse sections Figs. 6 to 9.

The boring tool is caused to rotate by rotating the working cylinder A, the piston being prevented from turning in the cylinder by means of two flats planed on opposite sides of the piston rod K, which fit into corresponding flats in the stuffing-box of the cylinder, as seen in Figs. 5, 9, and 14. The rotating of the working cylinder A, with the piston and boring tool, is effected by hand by the worm Q, Fig. 9, which is turned by the handle R, Figs. 9 and 10, and gears into a worm wheel fixed on the square shaft S. The brass pinion T, Figs. 2, 4, and 10, slides upon the shaft S, and gears into the teeth U round the circumference of the working cylinder A, Figs. 3 and 10; so that by turning the handle R the working cylinder is caused to rotate; and as the cylinder advances at each turn of the nuts H, the pinion T slides forwards with it along the square shaft S, as seen in Fig. 4. In an earlier construction of the boring machine, having a pair of cylindrical trunnions instead of the present spherical bearing C, a self-acting rotating motion was obtained from the spiral cam O that works the disc air valve N, by prolonging the spindle of the cam through the back end of the exterior cylinder B; and a couple of pauls on the end of the spindle worked into a ratchet wheel on the end of the square shaft S, which was also prolonged backwards for the purpose,

in the absence of the spherical bearing C. In practice however it has been found preferable to rotate the working cylinder by hand by means of the handle R, as above described, because the very rapid reciprocation was very severe upon the self-acting rotating motion, making it liable to derangement; and the hand arrangement, besides having the advantage of simplicity, avoids the necessity of prolonging the shaft S backwards, and thus allows of adopting the spherical trunnion C, which gives increased facility for turning the machine into any position desired for boring the holes.

The crosshead E slides forwards along the two screwed bars F as the working cylinder A is advanced inside the exterior cylinder B during the process of boring; and in front of the crosshead the nuts H H are fitted on the screwed bars F, against which the crosshead and with it the working cylinder are pressed by the pressure of the compressed air behind the working cylinder A. The nuts H are held from turning, and thereby prevented from going forwards, by four projecting stops upon their circumference, Fig. 11, which are caught by the catches I I below; these catches are kept pressed up by springs against the underside of the nuts; and between the two catches is placed a tappet J, so curved that it may be struck by the end of the piston rod when the latter has reached the outer extremity of its stroke, as shown in Fig. 4.

The mode of action of this advance motion is as follows. The compressed air is admitted by the flexible pipe L into the exterior cylinder B behind the back end of the working cylinder A, which is thus kept pressed outwards against the crosshead E, while the crosshead is kept in its place and prevented from going forwards by the nuts H, and these are prevented from turning by the catches I. But when the boring tool D has advanced $\frac{3}{4}$ inch, the distance due to one quarter turn of the nuts H, the outer end of the piston rod K, which is allowed a range of $\frac{3}{4}$ inch variation in the length of its stroke, strikes against the tappet J, as shown in Fig. 4, and depresses it sufficiently to make the catches I I release the projections on the nuts H; the forward pressure of the working cylinder and crosshead against the nuts then causes them to slip

past the catches and advance one quarter turn, thereby moving forwards $\frac{3}{4}$ inch upon the screwed bars F, when the next projections on the circumference of the nuts are caught by the catches I. This process is repeated for every $\frac{3}{4}$ inch bored by the tool, until the nuts reach the front end of the screwed bars F.

By this arrangement the boring tool is allowed to advance at whatever rate it may be cutting in the rock. When the rock is comparatively easy to bore and the tool is cutting rapidly, the projections on the nuts slip past the catches from one to another rapidly, and consequently allow each successive $\frac{3}{4}$ inch advance to occur more quickly; whilst when the rock is harder and the tool is cutting slowly, there is so much longer an interval between each release of the catches, and the advance of the nuts is less frequent, thus admitting of a greater number of strokes being made by the boring tool for each $\frac{3}{4}$ inch length of hole bored.

For winding back the working cylinder A by hand, when required for the purpose of changing the boring tool, the two worms M M, Fig. 11, turned by a handwheel, are geared into the nuts H H, as shown in Figs. 1 to 5. The friction of the worms also acts as a break to prevent the nuts from turning too suddenly, as it causes them to move gently when the projections on the nuts are released by the catches I I at each $\frac{3}{4}$ inch advance of the boring tool.

As the working cylinder A and crosshead E only press loosely forwards against the nuts H, neither the nuts nor the screwed bars F receive the slightest portion of the concussion from the blows of the tool; but the shock of each blow is conveyed direct to the air cushion behind the working cylinder A, in the back end of the exterior cylinder B. This effectually prevents crystallisation of the portions that are exposed to the direct concussion of the blow, and prevents any loosening of the several parts of the machine; it also relieves the carriage frame from the full shock of the blow, and steadies the boring cylinder.

At the outer end of the two guide bars F F are two screwed caps V V with steel points, Figs. 1 and 3, for the purpose of steadying the end of the machine against the rock. The outer end

of the boring tool D is steadied in the front bearing G, across the end of the two guide bars F, in order to compel the tool to bore straight when it meets with extra hard rock or quartz veins inclined to the direction of the hole; and by turning the handle W, the top bearing or step can be readily lifted out when the boring tool requires taking out for changing. During the working of the tool a jet of water is kept constantly playing into the hole; and this aided by the reciprocation of the tool effectually clears out all the loose material as fast as it is detached by the tool, without ever requiring the tool to be withdrawn as in hand labour for the purpose of clearing out the hole. In one of these boring machines working in the Roundwood Tunnel of the Dublin Corporation Water Works, the water is obtained from the top of the tunnel shaft, being a portion of that raised by the pumping engine which drains the tunnel, and the jet is thrown into the bore hole under a pressure of about 80 lbs. per square inch.

The mode of fixing the boring tool D in the piston rod K is shown in Figs. 12, 13, and 14, Plate 54, drawn half full size. The fixing of the tool is a very important point in the working of the machine, in order to ensure a thoroughly secure fixing and at the same time the means of readily and quickly changing the tool. The tool D is dropped into a socket in the end of the piston rod K, and the parallel cotter X being then passed through is fixed by the screwed gland Y, which presses the tool home to the bottom of the socket and secures the cotter endways by entering into the two notches in the front edge. The gland Y is prevented from turning back by a ratchet and spring Z; and for releasing the tool the spring is held back by a stud while the gland is unscrewed.

Several different forms of Boring Tools have been tried with the machine, but the results of experience have led to the adoption of the two forms only that are shown in Figs. 15 to 18, Plate 54, drawn half full size. The rose tool, Figs. 15 and 16, having two chisel edges at right angles to one another, is found the best form for commencing the hole and boring the first 9 or 10 inches length. The shape of this tool, in conjunction with the continuous rotary motion given to it between each stroke, prevents it from being led

away sideways when it meets with a vein of quartz harder than the rest of the rock and lying much inclined to the direction of the hole. The second tool, Figs. 17 and 18, used for completing the hole, is a chisel formed with the cutting edge in three bevils a little inclined to one another in both directions. The chisel shown in Figs. 19 and 20 was found the best for boring straight, but it could not be made to stand well, and was consequently abandoned. A hollow tool has also been tried, into which was inserted a water jet; and the exhaust air from the cylinder was also turned into it, which blew the water out from the point of the tool into the hole with considerable force. This was found a most excellent plan for keeping the hole clean; but in consequence of its complication and the liability of the jet orifice to become choked up with deposit from the water employed, it was abandoned and the separate water jet already described has been substituted.

The Frame and Carriage for this boring machine are shown in Figs. 21 and 22, Plate 55. The traversing carriage A is made very low, in order to allow of readily removing the debris from blasting; and upon it is mounted the upright pillar B, capable of swivelling round upon the carriage and having means for clamping it securely between the top and the bottom of the tunnel. The working cylinder C with the boring tool D is carried by the transverse frame or rest E upon the extremity of the horizontal jib F projecting from the centre pillar B. The arm G carrying the boring cylinder C can be traversed into any position in the frame E by means of a screw motion worked by the handwheel H; while the frame E can itself be turned round upon the axis of the horizontal jib F by the handwheel I working the worm wheel J, and the jib F can be lengthened or shortened by the handwheel K. By this means the boring cylinder C can be adjusted to any part of the face of the tunnel; and the spherical trunnion by which the boring cylinder is carried in the arm G allows of its being placed to bore in any position and direction. These several adjusting movements enable the tool to bore the holes in the exact line the miners may wish to place the shot, as the boring cylinder can work

either upwards, downwards, sideways, or at any inclination; and all the movements are at all times central and within easy reach of the attendant, whatever may be the direction or position of working.

The transverse frame or rest E is provided at each end with a pair of projecting steel points L L, which can be lengthened or shortened so as to clamp the rest securely against the rock, thereby relieving the horizontal jib F and the pillar B from the shocks produced by the blows of the boring tool. The steel points L L are attached to pistons inside the columns of the rest E, and by admitting the compressed air between the pistons the points are caused to strike out against the sides of the tunnel, and are then secured by self-locking catches. It is generally found sufficient however simply to wedge the hind wheels of the carriage in order to render the whole perfectly steady, without any necessity for clamping the carriage and rest against the rock.

The compressed air for working the boring machine is supplied by an Air Compressing Engine at the top of the shaft, driven by a small portable steam engine. The air compressing engine is shown in Figs. 23 to 27, Plates 56 to 59, and consists of two horizontal compressing cylinders A A, Fig. 23, fitted with air-tight pistons B packed with brass rings or cupped leathers, Fig. 25. On each end of the cylinder A are upright chambers C C, and on the top of each chamber are a pair of inlet and delivery air valves, so that there are two inlet valves D D and two delivery valves E E to each compressing cylinder; these valves are circular, and fit air-tight upon conical faces, as seen in Figs. 25 and 26. The four inlet valves D D are each suspended from a lever F, and in the original construction there was simply a weight on the outer end of the lever to cause the valve to shut when the piston B had drawn in sufficient air to fill the chamber C; it was found however that the valves did not work very steadily with the levers and weights, and they also shut before the piston reached the end of the stroke, so that part of the stroke was wasted in uselessly expanding the air in the chamber C. A cam G, Fig. 26, worked from the crank shaft H, was therefore added to each of the valve levers F, and the cam opens the inlet

valve at the commencement of each forward or suction stroke of the piston, and keeps it open till the commencement of the return or compressing stroke, when the valve is shut suddenly by the weight; and this arrangement has proved quite satisfactory. The delivery valves E E are shut by the back pressure, as soon as the compressed air is all forced out of the chambers C; they deliver the air into the air-vessels J, which are for the purpose of equalising the pressure of the air under the varying pressure of the stroke. A pipe K from each of the two air-vessels conveys the compressed air to a large wrought iron receiver, from which it is supplied for working the boring machine.

The two air-compressing cylinders A A, Figs. 23 and 25, are each 14 inches diameter with 18 inches length of stroke, and are placed at each end of a cast iron bed-plate; the pistons are worked by connecting rods from the double cranks H at right angles to each other, which receive motion from the countershaft L driven by the steam engine. By employing two cylinders of half area each for compressing the air, worked by cranks at right angles to each other, instead of a single larger cylinder, an advantage is gained in delivering the compressed air to the receiver more uniformly, and also the strain on the working parts is more evenly divided. The cylinders A are filled with water, which rises at each stroke to the top of the upright chambers C C, and the surplus water is forced through the delivery valves E, the object being to fill up every space with water at the end of the stroke, and so ensure every particle of air being forced through the delivery valves. To allow for leakage and waste of water, a supply is kept constantly flowing into the inlet valves D from the small pipe M, regulated by a tap; and the water forced through the delivery valves at each stroke keeps the air-vessels J J constantly filled with water up to the mouth of the pipe K, so that the compressed air is kept quite cool. The surplus water passing into the pipe K slowly accumulates in the large air receiver, out of which it is discharged occasionally.

The crank shaft H is driven at 22 revolutions per minute, and at each stroke the piston draws in the air through the inlet valve at one end of the cylinder, and compresses the air to six atmospheres

or 90 lbs. per square inch at the other end of the cylinder, discharging the compressed air through the delivery valve to the receiver. The minimum pressure maintained in the air receiver is 75 lbs. per square inch, and the maximum 125 lbs., the average being about 85 lbs. per square inch. From the receiver the compressed air is conveyed by cast iron pipes with india-rubber joints up to within 50 feet of the boring machine. It is then conveyed to the machine through an india-rubber pipe made with six-ply canvass and about 100 feet long, which allows the boring machine to be advanced or drawn back without undoing a single joint.

This boring machine is now employed in the construction of the Roundwood Tunnel for the new Dublin Corporation Water Works, of which a longitudinal and transverse section are shown in Figs. 21 and 22, Plate 55, where it bores the holes for blasting at one of the working faces. The tunnel is rectangular, 5 feet wide and 6 feet high, and is being carried through Cambrian rock of a remarkably hard and difficult character, interspersed with quartz veins. Six shot holes of 20 inches depth are usually fired at each blast, and these six holes of $1\frac{1}{4}$ inch diameter are all bored by the machine in about $3\frac{1}{2}$ hours; two chisels are used for each hole, which require fresh grinding before using again. With handwork however each of the same holes takes $2\frac{1}{2}$ to 3 hours for drilling, and requires usually about fifteen fresh tools before it can be completed. The practical value of this remarkable saving of time that is effected by the use of the machine is specially experienced in such work as tunnelling or other rock-blasting, where saving of time is generally of such great importance both in expediting and economising the work. The average rate at which the very hard rock is bored by the machine at the Roundwood Tunnel is about one inch per minute; and it has been found as the result of experience with the machine that it bores quicker and keeps the edge on the tool better by striking with less force of blow but with greater rapidity. The number of blows has been increased from 250 to 500 or 600 blows per minute, and the result is that one hole is now bored with two tools without

re-sharpening, instead of using five or six tools as formerly; and with one tool a hole of 26 inches depth is bored in the Dalkey granite without re-sharpening.

The following are the results of working in the Dalkey granite:—

1st hole	24½	inches	deep in	11	mins.	10	secs.
2nd „	19½	„	„	14	„	...	„
3rd „	9	„	„	5	„	55	„
4th „	4½	„	„	2	„	10	„
5th „	9	„	„	7	„	35	„
6th „	9	„	„	5	„	25	„

The following are the results of working in the remarkably hard rock of the tunnel at Roundwood:—

1st hole	8½	inches	depth in	3½	minutes.	
	6	„	„	8	„	
	9	„	„	3	„	
Total ...	23½	„	„	14½	„	
2nd hole	12	„	„	8	„	
	9	„	„	4	„	
Total ...	21	„	„	12	„	
3rd hole	6	„	„	5	„	
	9	„	„	10	„	
Total ...	15	„	„	15	„	
4th hole	10	„	„	6	„	
	9	„	„	3	„	
Total ...	19	„	„	9	„	
5th hole	10½	„	„	4	„	
	8	„	„	4½	„	
Total ...	18½	„	„	8½	„	
6th hole	14	„	„	10	„	

The average rate at which the machine now bores is, for the first portion of the hole, 10 and 11 inches depth in 4½ to 8 minutes; and for the second portion, 9 and 9½ inches depth in 3 to 3½ minutes.

The following special points of advantage have been experienced in this boring machine; and these may be considered as essential conditions to be fulfilled in a good machine for the purpose of

boring in hard descriptions of rock, and for standing satisfactorily the special wear and tear to which such machines are necessarily subjected.

The boring part of the machine with the tool is made very short, so as to allow it to work in any direction and position in the tunnel, in order that the blast of the hole bored may displace the largest amount of rock. The carriage frame carrying the working cylinder is also very compact, occupying little space and allowing the cylinder to be quickly adjusted into any desired position.

The reciprocating parts are very few in number, and are in the direct line of the blow; these are only the piston and rod in one piece of steel, and the tool secured in the piston rod so as to allow no play. Moreover in order to prevent crystallisation of the parts exposed to the direct concussion, a cushion of air is provided at the back of the working cylinder, which also relieves the carriage frame from the shocks of the blows. Also the tool being made to reciprocate with the piston, the hole is more easily kept free from the debris than when the tool is stationary and receives blows from a detached piston, as in other constructions of boring machines; and the strong water jet playing into the hole is found to keep it quite clear during the process of boring.

The advance of the tool is self-acting, and exactly at the same rate that the tool is cutting, however variable may be the nature of the rock; and whether the tool is cutting at the rate of 3 inches per minute in one part of the hole or only 1 inch per minute in another part, the advance given to the tool is exactly at the same rate that the boring progresses in each case; so that there is no risk of the piston at any time working beyond its proper range of stroke and striking the cylinder cover. The advance motion for the tool is obtained from the pressure that drives the piston, without the use of propelling gear, the absence of which greatly increases the durability of the machine. The turning motion for the tool also being connected to the stationary outer cylinder is freed from the source of derangement that would arise from the rapidity of the blows of the tool if the turning motion were connected to the reciprocating part. The motion for working the

valve is gradual and easy in its action, so that a very rapid action is obtained without any destructive shocks. The outer end of the tool is guided in a bearing, to prevent it from working to one side and getting jammed when meeting with an oblique vein of harder material.

The machine is arranged so that it can be brought to work again immediately after a set of holes have been blasted and before the debris is removed, which can be done whilst the machine is at work, the material being carried or thrown through the clear space left by the carriage frame; and a jet of air being left open near the face at the time of explosion soon dilutes and clears off the gases resulting from the explosion of the powder. This saves much of the loss of time which occurs with other machines in removing the debris before the machine can be set to work again. The compressed air on being discharged from the boring cylinder also serves effectively to ventilate the workings, and supplies fresh air to the miners.

Mr. Low exhibited specimens of the different sorts of boring tools used in the machine, and also samples of the hard Cambrian rock through which the tunnel was being driven, showing the quartz veins with which the rock was intersected.

The PRESIDENT thought there must be a good deal of difficulty in boring through such hard rock with the machine, from the tools requiring to be sharpened very frequently, and he enquired how often they were found to need sharpening in regular work.

Mr. Low replied that the tools required to be sharpened on the average for every 9 inches length of hole bored, on account of the particularly hard nature of the rock.

Dr. DOWNING said that through the kindness of the engineering staff and the contractor he had seen the boring machine at work in the Roundwood Tunnel, and had been enabled to collect a few data as to its action. As regarded the rapidity of boring the

holes, which was of course an essential consideration, he believed that 1 inch per minute might be taken safely as about the rate of the actual boring. He had seen a hole 20 inches long bored in 22 minutes, with boring tools $1\frac{1}{4}$ inch diameter like the specimens exhibited, and the same length had also been done in 18 minutes; and 20 inches in 20 minutes might be taken as the average rate of boring. It was not very easy to ascertain the exact time occupied per hole so as to include all the shifting of the machine, &c.; the practice was to draw the machine back after six or seven holes had been bored by it, and then a few more holes were made by hand in those parts of the face of the heading where the machine could not readily be worked; and all the holes were then fired nearly simultaneously. Including all these operations he believed 45 minutes for each hole would be a fair average to take for all the holes, including both those bored by the machine and by hand labour.

The PRESIDENT enquired how the hole was cleared out during the boring, and how often the tool had to be withdrawn for the purpose.

Dr. DOWNING replied that the tool was never withdrawn for the purpose of clearing the hole, which was cleared out by letting a jet of water under a high pressure play constantly into it during the working of the machine, and the water assisted by the reciprocation of the tool cleared out all the loose material as fast as it was detached by the tool. This was done much more effectually than by the ordinary mode of occasionally scraping out the hole when manual labour was used. The tool was usually withdrawn at about every 7 inches length bored, for the purpose of inserting a longer boring tool, the nuts upon the screwed guide bars being set back by hand. Before firing the charges in the holes the machine was drawn back to a sheltered spot, the distance varying with the progress of the work; at the time when he saw the machine working it had to be drawn back about 50 or 60 feet from the working face to the place of shelter. The machine ran upon a tramroad, and was drawn back very quickly, so that there was very little time lost in moving it.

Mr. H. W. HARMAN enquired what was found to be the comparative economy of the machine in working as compared with hand labour.

Dr. DOWNING said the time that the machine had been at work and the circumstances of the situation in which it was employed hardly admitted of any decided result being arrived at yet as to its economy; at present the cost of working with the machine appeared to be about equal to that of hand labour.

Mr. H. W. HARMAN enquired whether the present was the first application of the machine, and what was its cost.

Dr. DOWNING replied that the present work was the first application of the boring machine in regular work, and the machine now in use was the third that had been made, containing several improvements upon the two previous ones. Five more of the machines were now being constructed he understood, which were all intended to be employed upon the Roundwood Tunnel. The cost of the machine itself with its carriage was about £225, and the cost of the air-compressing engine about £210.

Mr. E. LEIGH enquired how much rock was removed per day in the tunnel by the aid of the boring machine.

Dr. DOWNING said the quantity of rock removed per day varied greatly, as it depended upon the hardness of the rock, which was very variable; but he did not know the actual quantity.

Mr. W. E. NEWTON remarked that one of the advantages of the present machine appeared to be the ingenious arrangement for the advance of the boring tool, whereby the tool was advanced exactly according to the rate at which the work progressed. With any direct mechanical connection, such as a crank motion or an ordinary feed motion, the tool would be advanced a definite distance at each blow, and neither more nor less under any change of circumstances; but in the present machine, by means of the self-acting nuts and screws governing the advance of the working cylinder, the total advance of $\frac{1}{4}$ inch allowed by the turning of the nuts might be obtained after a very few strokes; or, if the rock were too hard to admit of so rapid an advance, any number of blows might be given by the tool for each $\frac{1}{4}$ inch advance, the tool continuing to drive

away at the rock until it reached the end of the $\frac{1}{4}$ inch feed, and then the turning of the nuts allowed a further $\frac{1}{4}$ inch advance. By this means the tool was always advanced the right distance, just as in hand work, so as to follow up the work constantly according to the hardness of the rock; and the whole of the advance motion was entirely self-acting, without requiring the attention of the man in charge of the machine.

He enquired whether the expansion of the compressed air liberated from the cylinder of the boring machine was found to be attended with any disadvantage, by freezing the moisture in the exhaust passages.

Dr. DOWNING replied that no trouble had been experienced from the expansion of the compressed air, and the cold air thereby supplied at the working face was found a great advantage to the men in the tunnel by the thorough ventilation which it produced.

Mr. T. WATERHOUSE enquired what was the weight of the boring machine, and whether it was applicable also to sinking vertical shafts.

Mr. LOW replied that the weight of the machine was about 2 tons including the carriage; and it could be employed for sinking a vertical shaft, in which case the weight would be only about 30 cwts. including the frame.

Mr. J. MURPHY remarked that the frequency with which the boring tools required sharpening would depend much upon the quality and temper of the steel employed; and perhaps a harder quality of steel might be procured for the purpose, which would stand for a longer time without sharpening. He understood steel was now made of such superior quality as to be capable of cutting and turning steel tyres after hardening; and if that were tried for the boring tools it would probably save much of the trouble of sharpening them. The form of the boring tools employed in the machine appeared new, as he had not seen that form used in boring by hand; and the peculiar shape might perhaps account in part for the greater durability of the tools when worked by the machine than in hand work, since the shape of the tool had no doubt a great effect on the efficiency

with which the work was done; but if the same shaped tools were employed with the machine and by hand he did not understand why they should be found to require sharpening so much less frequently with the machine, as the action upon the tool appeared very similar in both cases. In the present machine there was some appearance of complication, arising probably from the number of small parts of which it was composed; but the utility of a boring machine when applied for sinking vertical shafts had been strongly exemplified at Cardiff, where one of Messrs. Mather and Platt's boring machines had been employed with great success to bore for water. That machine bored a well of 18 inches diameter at the rate of 20 to 30 feet per week to a depth of 295 feet, chiefly through the old red sandstone rock, from which excellent water was obtained; and the well now yielded a supply of about 500 gallons per minute, which was used for brewing purposes. Another of the same machines had been employed also at Middlesbrough to bore for coal, and had bored a hole of 22 inches diameter part of the way and afterwards 18 inches diameter to a total depth of 1300 feet through new red sandstone; and he had no doubt the machines would soon be brought into practical operation for various purposes. Had the practicability of sinking wells in that ready manner been demonstrated earlier, it might perhaps he thought have been expedient to try boring for water in the immediate neighbourhood of Dublin, before bringing it in from so great a distance as Roundwood.

Mr. J. ANDREWS, resident engineer upon the works in progress of the Dublin Water Works, remarked that, in reference to the relative durability of the boring tools when worked by the machine and by hand, the cause of the tools requiring less frequent sharpening with the machine was probably to be found in the fact that the tool being attached to the piston in the working cylinder gave the blow on the rock and was itself the hammer; it was also guided with precision in the blow, and turned with regularity, so that the point or chisel struck with a solid and even bearing in the bottom of the hole. Moreover the force of the blow was given to the tool by the compressed air behind the piston in the working cylinder,

which had not the damaging effect upon the tool occasioned by the dead blow of a hammer. In the latter case not only did the hammer soon destroy the end of the tool on which it struck, but the chisel end also was soon rendered useless by the unsteadiness with which it was held and turned by the hand, the blow being given when only a corner of the chisel touched in the bottom of the hole, which caused the sharp edge to be chipped and broken by a few strokes. The length of stroke of the tool in the machine was about 4 inches, and the lighter blow given by it at each stroke as compared with hand work was more than made up for by the very much greater rapidity of the strokes with the machine, whereby the hole was bored in a shorter time and with less injury to the tools.

The PRESIDENT enquired what was the rate of advance of the tunnel per day at the part where the machine was now working; and what had been found to be the practical advantage of boring by the machine as compared with hand labour.

Mr. J. ANDREWS replied that in the very hard lower Cambrian rock in which the machine was now working the rate of advance of the tunnel was from 6 to 8 inches forward per day, the size of the tunnel being about 6 feet high by 5 feet wide. With regard to the comparative advantage of boring by the machine or by hand, he had seen a hole of from 20 to 24 inches depth bored by the machine in from 15 to 20 minutes in a part of the rock not intersected by quartz veins, and three tools only were required to perform this work; but to do the same work by hand labour would have required two men for about 2 hours, and would have taken as many as from 20 to 30 or even 40 tools. The expense of boring by the machine was about equal to that of hand labour, but the machine had not yet been at work long enough to do more than about 12 or 15 yards of direct work.

The PRESIDENT enquired whether by putting a sufficient number of men upon the work the tunnel could be driven as fast by hand labour as by the machine.

Mr. J. ANDREWS said there was so little room for working at the face of the rock, on account of the small size of the tunnel, that the machine would bore more holes in a given time than it

was possible to do by hand labour under any circumstances. Notwithstanding this advantage however the actual rate of advance of the tunnel had not been greater since the machine was used than before its employment. This was on account of the small size and rectangular form of the tunnel not admitting of the full benefit being derived from the machine, as much of the work in getting out the corners had still to be done by hand; and much time was taken up in shifting the working parts into new positions, hammering off the shaken rock, and getting the debris out of the way. Moreover the frame of the present machine was found rather clumsy in the confined space of the tunnel, and a smaller frame which was now being made, better adapted to the situation, would enable the work to be carried forwards much more rapidly.

Mr. J. MURPHY enquired what was the difference between the machine now described and that employed for excavating the large Mont Cenis tunnel between France and Italy, which he understood was advancing at the rate of about 3 feet per day.

Mr. J. ANDREWS believed the boring tools were similar in the two machines, but the Mont Cenis machine consisted of a large frame carrying eight boring cylinders and tools working independently by compressed air; an adit was driven by this means 9 feet square, and the whole size of the tunnel was afterwards completed by hand labour to about 26 feet by 24 feet. As many as 80 holes 3 feet deep were bored in the adit face before blasting. Each boring part of that machine could only work horizontally, and was longer and larger than in the present machine, in which the boring tool could be turned to any angle and set to work either horizontally forwards or sideways or vertically or at any intermediate inclination, by means of the several adjustments provided in the frame of the machine, so as to suit the best position and direction for inserting the hole, in order to obtain the greatest amount of shaken rock at one blast. A model of the frame was exhibited, showing the arrangement for allowing of turning the tool to work in any desired direction.

Mr. W. E. NEWTON enquired whether the machine could not be arranged for working two boring tools so as to bore two holes

at a time instead of only one. As the rate of excavating the tunnel at present by the machine was apparently hardly greater than by hand work, he suggested that the tunnel might be driven even faster by hand labour by employing a few more men, unless the machine could be arranged to bore two or more holes at a time.

Mr. J. ANDREWS replied that the machine could readily be arranged to work two or more boring tools at a time, and would have been employed in that manner had the tunnel been large enough to allow of working more than a single tool conveniently.

Sir JOHN GRAY, M.P., chairman of the Dublin Water Works, remarked that it must be borne in mind that the Roundwood Tunnel, in which the machine was now working, was so very small that in working by hand labour there was only room for boring one hole at a time, for which two men were required, one to hold the boring tool and the other to strike it with the hammer. In the case of any given hole the machine bored much more rapidly than could be done by hand, as was shown by the fact that in regular working the machine bored holes of 20 inches depth in 20 minutes each, which took 2 hours at least by hand labour. The machine was at present indeed only in an experimental condition, having been tried two or three times previously in different frames, the great object throughout having been not so much to save expense as to economise time; for the materials to be bored through in the formation of the tunnel had proved so much harder and more difficult of removal than had been expected, that it was found the tunnel could not be completed by hand labour within the time stipulated, and the machine had therefore been tried with the view of expediting the work. The first machine was tried for the purpose about twelve months ago, but did not prove sufficiently effective; and the second machine, though containing some improvements which made it a little more effective, still did not answer: the machine now in use, the third that had been tried, was the first which had performed any satisfactory work, and it certainly did bore in a narrow tunnel

much more rapidly than could be done by hand labour. If there were a larger space to work in, so that two or three of the boring tools could be put to work by the machine at the same time, the excavation would of course be proceeded with much more rapidly; and owing to the inconvenience of the present frame of the machine in the confined space of the tunnel, there was not sufficient facility for turning the boring tool to work at the different angles at which it was desirable that it should be employed in order to derive the full benefit from the use of the machine and reduce the amount of hand work in boring the holes. At present the machine was practically only able to work within a certain range of angle, so that only a comparatively small portion of the work of driving the tunnel was really done by the machine, and the rest had still to be done by hand labour. The practical result therefore up to the present time had not been so satisfactory even in regard to time as could have been wished, the machine not having produced a much more rapid rate of progress in driving the tunnel, notwithstanding the very great increase of rapidity in boring each individual hole by the machine.

Mr. C. COCHRANE observed that, from the information which had been given respecting the practical working of the machine in the Roundwood Tunnel and the actual rate of progress of the work, it would appear that a very large proportion of the whole time must be absorbed in the mere adjustment of the machine between the boring of each successive hole, and also in executing the large proportion of corner work which had to be done by hand labour; for it was impossible otherwise to understand how there could be so little economy of time effected by using the machine, considering the very great increase of rapidity in boring the holes by the machine as compared with hand labour. He suggested that there might also be a good deal more delay in removing the machine before firing the charges than had been mentioned; because, although the machine ran upon a tramroad on which it could be drawn back quickly, there was the flexible air tube in the way, which would have to be removed first to avoid obstructing the passage of the machine.

Mr. NEVILLE, engineer to the corporation of Dublin, said there was no doubt the greatest delay arose from the inconvenience and loss of time in moving the present frame of the machine in the small tunnel; a new frame was now being made for the purpose, with the modifications that had been found desirable for adapting it better to the circumstances of the situation, and when that was completed it was expected the progress of the work would be much more rapid.

The PRESIDENT remarked that it was evident the machine had not yet been long enough at work to allow of its full advantages being realised; but it was certainly one of great ingenuity, and from the particulars that had been given respecting its performance under the disadvantageous circumstances in which it had at present been employed there seemed no doubt that it would ultimately prove a valuable machine for rock boring.

He moved a vote of thanks to Mr. Low for his paper, which was passed.

The following paper, by Mr. Parke Neville, Engineer to the corporation of Dublin, communicated through the President, was then read:—

ON THE NEW DUBLIN CORPORATION WATER WORKS FOR THE SUPPLY OF WATER FROM THE RIVER VARTRY.

By Mr. PARKE NEVILLE, of Dublin.

The supply of Water to the city of Dublin was for several centuries obtained entirely from the River Dodder, Fig. 2, Plate 61, across which a weir had been constructed near Templeogue, at about 5 miles distance from Dublin, whence the water was and is still conveyed into Dublin by an open conduit called the "city water-course." In 1775 the water supplied from this source was found so bad and insufficient that the corporation arranged for obtaining what was then considered an ample supply of water from the Grand Canal; and in 1806, the quantity having again become insufficient, a better supply was procured from the Grand Canal and also from the Royal Canal, which was measured by overfalls of a certain length. This last arrangement was made to extend over a term of sixty years, and under it Dublin has been supplied up to the present date.

The Royal Canal supplies water to the north side of the city, and the Grand Canal and city water-course to the south side; the water for the former being received into the city basin at Blessington Street, and for the latter into the James Street and Portobello basins. The level of the water in the north basin is 78 feet, and in the south basin 76 feet, above ordnance datum, which is the level of low water of a 12 foot tide. The surface levels of the lowest parts of the city along the quays range from 20 to 28 feet above this datum, and the head of water in those parts is therefore only about 50 feet, while over the average of the city it is not more than 25 feet, and some parts are at too high a level to be supplied at all.

The water obtained from the Dodder is of a soft quality, and would be very good for domestic use, were it not for the pollutions received from paper and other mills, which have been allowed to be erected from time to time along the course of the river. The water of the canals is very hard, having a hardness of 15 to 16 degrees by Dr. Clark's test, a hardness of 1 degree being that due to 1 grain of chalk dissolved in 1 gallon of distilled water; and the canal water is also liable to great pollution.

For many years the want of a really good supply of soft water and at high pressure for the city and the suburban districts was strongly felt, and various plans have been proposed for obtaining a new or improved supply. In 1857 it was proposed to obtain a supply from the canals at a higher level, where their water was more pure; and it was afterwards proposed to obtain water from the Liffey at about 20 miles above Dublin. But finally in 1860 the whole question of the water supply to Dublin was referred to a royal commissioner, Mr. Hawkshaw, who recommended obtaining a supply of water from the River Vartry. An Act was passed in 1861 for the purpose of carrying this into effect, and the work was commenced in November 1862, the amount of the contract for the whole being £274,000.

In Fig. 1, Plate 60, is shown a plan of the drainage area from which the supply of water is obtained; and Fig. 2, Plate 61, is a general plan of the whole course of the water works from the River Vartry to Dublin. Fig. 3, Plate 62, is a longitudinal section along the line of the works.

The River Vartry rises at the southern base of the Great Sugarloaf Mountain in the county of Wicklow, Figs. 1 and 2, and flowing in a southerly direction through a very thinly populated country reaches the Devil's Glen at a distance of about 10 miles from its source. After passing over the fall it continues through the glen to the Broad Lough, from which it flows into the sea at Wicklow. The water of the Vartry is collected entirely from a clay-slate district, and is peculiarly soft and pure, and during the greater part of the year quite free from all colour; it is almost identical

in analysis with the Loch Katrine water which now supplies Glasgow.

Rain gauges have been set up in different positions and at different elevations within the drainage area of the catchwater basin, Fig. 1, which have been accurately observed for more than four years; and they have registered the following as the average annual rainfall over the whole area:—

In 1861	.....	60·87 inches.
1862	.....	60·48 „
1863	.....	44·85 „
1864	.....	48·39 „

This is a much larger rainfall than was originally calculated to be yielded by the district, and leaves no doubt as to the sufficiency of the supply; and the whole of the water from the catchment is available for the waterworks purposes, as all mill rights &c. along the course of the river have been bought up, and no compensation water has to be given off.

The place selected for the formation of the storage reservoir is at Roundwood, Fig. 1, about 7½ miles below the source of the river; and at the point A, where the great embankment for the reservoir has been constructed, the bed of the river is 632 feet above ordnance datum, or 520 feet above the highest part of Dublin. The drainage area above this point is 13,992 acres or 22 square miles, and the area of the reservoir will be 409 acres. When full, the level of the water will be 692 feet above the datum; and the reservoir will hold about 2400 million gallons of water, or 200 days' supply for the city and suburban districts, taking the daily quantity required at 12 million gallons; but this is much in excess of what it is expected will actually be required for many years, as the present population to be supplied is only about 340,000. The quantity calculated for would supply a population of 400,000 with 25 gallons per head per day, and leave a surplus of 2 million gallons per day for manufacturing and other purposes.

The main embankment of the Roundwood reservoir is 66 feet high in the deepest part, and the greatest depth of water in the reservoir is 60 feet. The embankment is 2000 feet long on the top, and has a public road 24 feet wide carried over it; the entire breadth

of the bank at the top is 28 feet, and at the base in the deepest part 380 feet. The outer slope is $2\frac{1}{2}$ to 1 and the inner 3 to 1; and the total quantity of earthwork in the embankment is 320,000 cubic yards. The puddle wall is 6 feet wide at top, and about 18 feet wide at bottom on the level of the surface of the old river bank; and throughout its entire length the puddle wall is carried down to the solid rock. The by-wash or waste weir is 300 feet wide, and discharges into the old river course, as shown at B, Fig. 1.

A tunnel for the outlet from the reservoir is formed under the eastern end of the embankment, by excavating an open cutting into the rock, and then arching it over with a semicircular arch of ashlar stone 4 feet thick; it is 14 feet high by 14 feet wide in the broadest part. Near the centre of the tunnel is a brick plugging 20 feet thick, carefully toothed into wedge-shaped recesses in the solid rock. Through this plugging are laid two cast iron pipes of 48 and 33 inches diameter; the larger of which is intended chiefly as a sluice for lowering the water level in the reservoir quickly, and is to be continued into the tail of the by-wash, near where the latter joins the old river course. The 33 inch pipe is for conveying the water into the circular distributing basin, from which it passes by conduits to the filter beds, and thence into the pure water tanks. In the valve chamber at the outer end of the embankment tunnel a very complete set of stop-valves is placed for enabling both the 48 and 33 inch pipes to be worked as may be required. At the inner end of the embankment tunnel is built a water tower, into the bottom of which the 33 inch pipe is carried; and in the sides of the tower are inlet openings, with valves fixed on the inside, for enabling the water to be drawn from the reservoir at different levels, in order that it may be drawn off in the best state for use.

The filter beds and pure water tanks cover about 6 acres. There are seven filter beds, each 205 feet long by 110 feet wide; and any six of these working at the same time will be sufficient to filter the required quantity of water, so that one can always be spared for the purpose of cleansing and washing the sand and for repairs. The filtering material employed will be sand, gravel, and

broken stone. The two pure water tanks which receive the water from the filters hold 2,730,000 gallons of water each, and are placed so that four of the filters are on one side of them and three on the other, the remaining space on the latter side being occupied by a sand-cleansing machine and store for the sand. From these tanks the water will be carried for a distance of about 700 yards in a cast iron pipe, 42 inches diameter, laid with a fall of 6 feet per mile, until it reaches the tunnel, into which it is carried for a length of 120 yards so as to get to the solid rock.

This tunnel is 4367 yards long or nearly 2½ miles, the entire length being through very hard Cambrian rock full of quartz veins. Twenty-one shafts have been sunk along the course of the tunnel, as shown in Fig. 1, from which the miners work right and left; and up to the present date the headings from five of the shafts have met, and 3160 yards or 1¾ miles have now been tunnelled. The tunnel is 6 feet high and 5 feet wide, and has a fall of 4 feet per mile throughout. This work has turned out much more difficult and tedious than was anticipated, chiefly owing to the hardness of the rock, and the great quantity of water met with in the shafts and headings, which requires very large pumping power; and it is calculated that the tunnel cannot now be completed before the latter end of next year.

At the lower or Dublin end of the tunnel there will be a relieving tank and measuring weir, where the water passed down for the supply of the city will be gauged daily. From this tank, in which the surface of the water will be 606 feet above the ordnance datum, a 33 inch main conveys the water to the distributing reservoirs at Stillorgan, having a self-acting stop-valve at its junction with the tank, to prevent flooding in the event of a pipe bursting.

The average falling gradient of the main is 20 feet per mile, and it passes the village of Newtown Mount Kennedy, near which there is another self-acting stop-valve at the point C in Figs. 2 and 3; it then passes along the coach road through the Glen of the Downs to the Kilmurray relief tank, which is about 7 miles from the lower end of the tunnel. This tank is circular, excavated out of a gravel

hill, and lined with puddle covered with pitching. The end of the main delivering into the tank has a 33 inch double-acting stop-valve, and there is a self-acting valve on the mouth of the main leaving the tank. The surface level of the water in this tank is 473 feet above ordnance datum.

The main is then brought down again to the road, and continued 3 miles to the Kilcrony relief tank, situated on the top of the southern bank of the Dargle, and commanding a remarkably fine and extensive view. Owing to the loose character of the quartz rock in which this tank is excavated, it has to be lined with puddle. The water level is 414 feet above the datum, and the tank is provided with inlet and outlet valves similar to those at the preceding tank.

The main is then carried down under the Dargle River, and afterwards under the Cookstown River to the Rathmichael relief tank at $3\frac{1}{2}$ miles distance, which is excavated in the rock and happens to be situated exactly on the junction of the granite with the clay-slate, so that one side of the tank is in granite and the other in slate. This is a square tank, and puddled; and the level of the water in it is 341 feet above the datum. Here also there will be a double-acting stop-valve and a self-acting valve, as described for the other tanks.

The main is then continued for nearly 4 miles, partly along the Wicklow Railway, having a self-acting valve and stop-valve inserted in this length at D, Figs. 2 and 3; and it terminates at the two distributing reservoirs at Stillorgan, making a total distance of about $16\frac{3}{4}$ miles from the lower end of the tunnel.

The water area of the Stillorgan reservoirs is 18 acres, and their average depth about 20 feet, so that the two will contain about 90 million gallons of water. The surface level of the water in the upper reservoir is 274 feet, and in the lower 271 feet above the datum; and the latter is therefore the working pressure for the supply of Dublin, the distance being $4\frac{3}{4}$ miles from the city boundary, making the total distance from the Roundwood reservoir to Dublin about $24\frac{1}{2}$ miles. The 33 inch Vartry main is laid into each reservoir, and the stop-valves are so placed that either

reservoir can be worked at pleasure; the two reservoirs are also connected together by a pipe laid through the dividing embankment.

At the lower reservoir is constructed the valve-house and screen-chamber, into which mains from each reservoir are laid, together with one in direct continuation from the Vartry main; and by the system of valves placed in this chamber the water can be drawn from either of the reservoirs, or direct from the Vartry main. In the latter case it is not exposed in the reservoirs at all, which in warm weather it is calculated will be a great advantage, as the water will thereby be delivered cold and pure. At the same time there is the security of having always about 10 days' supply of water in the reservoirs in case of any accident to the main pipe, thus allowing ample time for any repairs.

The screen-chamber will contain a set of copper wire screens, through which the water will be strained before entering the delivery mains, so as to remove the possibility of any small substance being carried into the mains. These screens will be cleansed periodically by a hose and jet, and the arrangements of valves are such as to allow of this being done at any time without interfering with the regularity of the supply.

A double line of 27 inch mains are laid out of the screen-chamber, with self-acting valves, extending $4\frac{3}{4}$ miles to the city boundary. The double line has been laid with the view of preventing the possibility of any stoppage in the supply by the bursting of a main or the necessity for any occasional repair; and connections are made between the two mains at three points, with groups of stop-valves to afford the means of turning the water from one main into the other as occasion may require. Air valves have been placed on all summits, and scouring valves in all hollows.

The total cost of the entire works when completed, including £60,000 spent in the extension and improvement of the pipes within the city, will be less than 30*s*. per head of the population supplied, which is a very low amount as compared with the cost at other places.

Mr. NEVILLE mentioned that the paper just read had been prepared simply as a general description of the works, to serve as a guide for the Members in connection with the excursion to be made on the following day for visiting the works, and not with a view of entering fully into the details of the works.

Mr. J. MURPHY enquired whether any attempt had been made to procure water in Dublin or the neighbourhood by boring, before the present plan of supply from Roundwood was decided upon. He did not think it was sufficient to infer merely from geological indications the supply of water that would be obtained from wells, in the absence of an actual trial by boring; because boring frequently brought to light facts which had not been anticipated. In the boring for coal at Middlesbrough, which he had previously mentioned, instead of the coal that was expected to be found, a bed of pure rock salt 100 feet thick was met with, the existence of which had not been suspected from any previous indications.

The PRESIDENT observed that one objection to obtaining the water supply by boring would be the want of gravitation in that case for the distribution of the supply. The great advantage of the scheme now being carried out would be that the gravitation would save all pumping and boring; it entailed of course the expense of damming up the water in the first instance and conveying it into the city, but all heavy expense afterwards for constant pumping was then avoided. This had been the view taken of the question at Glasgow, where the water supply had formerly been by pumping from the Clyde; but that plan had now been abandoned and the water was brought in by gravitation from Loch Katrine, as described in the paper read at the meeting of the Institution in Glasgow last year. In the new Dublin Water Works, he thought there might be some difficulty in filtering the water, owing to the quantity of sand which would perhaps be found to be brought down by the water from the extensive drainage area from which the water was collected. When the water for Glasgow had been drawn from the Clyde it contained so much sand that there had been great trouble in filtering it, owing to the sand getting into the filter beds and stopping their action, in consequence of which they

required to be cleaned often. Perhaps however the Vartry water might not have so much sand in it as the Clyde water.

Sir JOHN GRAY, M.P., chairman of the Dublin Water Works, said that before the gravitation plan was decided upon a proposal had been made to try the boring process for getting water; but they had ultimately come to the conclusion that a great many wells would have to be sunk and a large number of pumping engines erected in order to give the required supply, and that that mode would be much more costly on the whole and not nearly so effectual as the gravitation plan now being carried out. Moreover water taken from the strata underneath Dublin would be largely impregnated with lime; for near his own residence only two miles from Dublin and on nearly the same geological formation the hardness of the well water was in one case found to be as much as 91° on Dr. Clark's scale (in which a hardness of 1° is that due to one grain of chalk dissolved in one gallon of distilled water, the hardness being the property of destroying soap). The well water in Dublin was not so hard as this, but it varied from 20° of hardness upwards, and was therefore considerably harder than the canal water. By carrying out the gravitation plan the supply would be self-acting, with a high pressure for fire service and for general house service, and a better quality of water would be obtained at a much cheaper rate than would be possible in any other way.

Mr. NEVILLE remarked that another objection to the pumping plan was that the geological formation on which Dublin stood was not such as to warrant by any means the anticipation of a sufficient water supply. It was quite a different case from that of Cardiff, which had been alluded to in the previous discussion, where it had been stated that a supply of good water had been obtained from the old red sandstone by boring.

Mr. W. E. NEWTON enquired upon what terms it was proposed to supply the water in Dublin, whether by meter or by a charge upon the rental of the houses.

Sir JOHN GRAY replied that both modes of charging for the water supply would be adopted. The house supply would be at a

poundage rate of 1*s.* in the pound on the valuation of the property; this would be a compulsory rate, the inhabitants being obliged to pay this rate for the water, whilst on the other hand the corporation was compelled to supply the water. The amount of the rate however was not so high as the same nominal rate in England, where a public assessment was usually made upon the rental of the property; for in Dublin a public valuation was made of all property, which was determined by law to be on an average 25 per cent. below the rental of the property; so that the rate of 1*s.* in the pound was equivalent to only 9*d.* in the pound in England, and in fact rather less, owing to the lower proportionate rentals of property in Dublin as compared with most large towns in England. The other mode of supply, by meter, was intended principally for manufacturing purposes, and an ordinary meter rent would be charged for keeping the meters in repair, and a fair rate for the water supplied. The charge for the water was not fixed, but the rate would be matter of agreement in each case.

Previous to the commencement of the works now in progress the old system of rating in Dublin had been by a sliding scale, which pressed very unequally on the poorer classes. It began at 5*s.* per annum for a certain class of perhaps very small houses, and rose to 10*s.* and 15*s.* for other classes; and 30*s.* per annum had been the highest rate that could be charged upon any class of house. There was also another very defective arrangement under the old system, by which a bath, a water-closet, and a stable were each charged for separately in addition; in consequence of which it was calculated that a person living in a very moderate sized house might have to pay for water as much as 2*s.* 3*d.* in the pound on his valuation, whilst another person living in a larger house but without those extras might be paying no more than from 3*d.* to 4*d.* in the pound for water supply. It had therefore been concluded that the old system of charging was very unjust, and that it would be better to have the equal method of rating at 1*s.* in the pound on the valuation of all property; and it had also been satisfactorily ascertained beforehand that this amount of rate would not only never have to be exceeded, but that it would do

more than pay for all the expenses of the works, leaving a large fund in the hands of the corporation for the public benefit, and allowing ultimately of a reduction in the rate itself.

The PRESIDENT thought the rate of 1*s.* in the pound in Dublin, which was equivalent to only 9*d.* in the pound in England, was a very moderate amount. In Glasgow the rate had been at first as much as 1*s.* 2*d.* in the pound on the rental, but it had now been reduced to 1*s.*, which was found ample, leaving a large amount of profit, and he thought it very likely that the rate would be still further reduced before long.

With regard to the quantity of water proposed to be supplied to Dublin, 12 million gallons per day to a population of 340,000 appeared small in comparison with that in Glasgow, where the population was not one half more than in Dublin but the quantity of water supplied was 23 million gallons per day. No doubt there was great extravagance and waste of water in Glasgow to account for so large a consumption per day; and it remained to be seen whether the population in Dublin would be so much more careful of the water as to find the smaller supply sufficient.

Sir JOHN GRAY said the water supply to Glasgow was certainly extravagantly large, and not only was more water used there than was at all necessary but there was also a very large waste indeed. He understood that means were being devised for reducing the waste, and that it had already been reduced as much as 8 or 10 million gallons per day by a better mode of inspection. The possibility was contemplated of a large waste occurring in Dublin, unless provision were made to prevent it; for at present it had been ascertained that under the existing system of supply there was more water wasted in Dublin than was used. It had therefore been determined to prevent such excessive waste under the new supply, and although the new works would not be completed for more than a year, the water arrangements and fittings of every house were already being inspected, and it was intended to have a system of house tap service of the most perfect kind that could be obtained, in order to prevent any needless waste, and in that way to render the water supply quite sufficient for the

requirements of the population, though not so large per head as that of Glasgow. In Manchester, which was considered to be very well supplied with water, the daily supply per head was under 21 gallons, and he understood that quantity was found amply sufficient; and the supply contemplated for Dublin of 12 million gallons per day would therefore be much larger than the Manchester supply, as it would be equivalent to as much as 35 gallons per head per day to the present population of 340,000.

Mr. NEVILLE remarked that the quantity of water required for manufacturing purposes in Glasgow was from ten to twenty times as great as that employed for the same purposes in Dublin, which might partly account for the much larger consumption in Glasgow.

The PRESIDENT believed the great waste of water in Glasgow was in connection with the house supply, though he could not understand how any one could manage to waste more than 25 gallons per head per day, and he considered a much smaller quantity would be amply sufficient for all reasonable requirements.

Mr. J. MURPHY thought that with such an abundant supply of water as would be obtained from the extensive watershed at Roundwood it would be a great mistake to limit the quantity of water to be used in such a city as Dublin, for he considered that nothing was more conducive to the salutary condition of a town than a plentiful supply of water. Moreover that which was spoken of as waste of water ought not to be regarded as altogether wasted, for it passed into the sewers and cleansed them, by removing impurities which could not be removed by other means; and he believed this mode of cleansing the sewers was found preferable to flushing them at intervals, which he understood had been attended with injurious effects in many cases in consequence of the violent current of water washing away the mortar from between the bricks of the sewers and thereby causing them to fall in.

The PRESIDENT suggested that if the flushing of the sewers were placed under the control of the corporation it might be done at the most suitable periods for efficiently cleansing the sewers, which would be better than allowing an indiscriminate waste of water, when one part of the sewers might perhaps be

clean where the water was much wasted, and another part foul where there was less waste.

Sir JOHN GRAY explained that the whole management of the water, sewerage, and streets of Dublin was now in the hands of the corporation; and great advantage was expected to result from the unity of action that would thereby be obtained. With regard to waste of water he believed it was a mistake to suppose that any benefit as to flushing of sewers arose from a continual waste running into the sewers; for it had been found by experiment that a continual dribble of water which might be very wasteful to the water supply had very little beneficial effect in cleansing the sewers; and he believed that a good system of periodical flushing would do far more to remove refuse matter and carry off putrescent gases at one tenth the expenditure of water. There would be no difficulty in arranging for an extensive and frequent flushing of the sewers in Dublin, as there was a plentiful supply of water to be obtained for that purpose from the upper part of the river Dodder, without requiring any of the water from Roundwood to be expended in that way. But any waste of water from the taps in a house tended to cause damp and ill-health, while it would produce no beneficial effect whatever in the sewers. The merest thread of water, barely visible but constantly flowing under high pressure, was sufficient to produce a waste of more water than the entire household would consume; and such seemingly small waste from each house throughout the city would cause more water to be wasted than was actually made use of out of the whole water supply. A prime requisite therefore in town supply was sound and durable taps.

Mr. J. MURPHY enquired whether the water supply was intended to be constant or intermittent, as the value of a constant supply was far greater than that of an intermittent supply, where the quantity supplied per day was comparatively small.

With regard to the supply of water by meter for manufacturing purposes, it had been mentioned that the charge for the water in that case was to be determined by an agreement between the water company and the consumer; and he thought that difficulties

might frequently arise in coming to an agreement which would be considered satisfactory on both sides. At his own works at Newport in Monmouthshire the cost of water according to the rate charged by meter would have amounted to as much as £60 to £70 a year for a supply of water to the smith's forge and engine of 40 horse power; but he had then bored for water, and succeeded in obtaining a supply by that means, after which the company had offered to supply water to the works for £10 per annum. The mode of rating was also a matter of dispute in Newport, and it was therefore contemplated by the corporation of that town to make a purchase of the water works, and establish a more satisfactory system of supplying manufacturing premises.

Sir JOHN GRAY remarked that as the water supply of Dublin was now entirely in the hands of the corporation the inhabitants who elected the corporation were really the controlling power, and it was not anticipated therefore that there would be any difficulty in coming to a satisfactory arrangement for the charge for water supplied by meter for manufacturing purposes. No decision had yet been arrived at upon the subject, but it was the intention of the corporation to ascertain the arrangements existing in several of the principal manufacturing towns in England and Scotland, and by taking an average of their charges to arrive at a just price for the water supplied to the manufacturers in Dublin. Whatever the amount of the profit derived from this source, it would go not to a private company but to the corporation, and would thus be shared in by all the inhabitants.

In reference to the nature of the new water supply to the city, it was intended to be constant, and would have the advantage of being also at high pressure. The water would be supplied by gravitation from the service reservoir at Stillorgan, about five miles distant from the city, and with a head pressure amounting to 250 feet above the lowest street level.

The PRESIDENT proposed a vote of thanks, which was passed, to Mr. Neville for his account of the Water Works, and to Sir John Gray for his kindness in giving the further information that had been asked for in connection with the subject.

The PRESIDENT proposed a vote of thanks, which was passed, to the Local Committee, and the Honorary Local Secretaries, Dr. Downing and Mr. G. Arthur Waller, for the excellent arrangements they had made for the meeting of the Institution in Dublin; and also to the Provost and authorities of the University of Dublin for their kindness in granting the use of the Examination Hall for the purpose of the meeting; and to the several Railway Companies for the special facilities they had so kindly afforded to the Members for attending the Meeting in Dublin and the Excursions in connection with the meeting.

The Meeting then terminated. In the afternoon the Members visited the various engineering establishments and other works which were opened to their inspection during the days of the meeting.

In the evening the Members and their friends dined together at the International Exhibition Building, in celebration of the meeting of the Institution in Dublin.

On Thursday, 3rd August, an Excursion was made by the Members from Dublin by special free train, granted by the Dublin and Wicklow Railway Company, to visit the works in progress of the Dublin Corporation Water Works at the Stillorgan and Roundwood Reservoirs, proceeding from Bray through the Glen of the Downs along a portion of the line of Pipes; and returning from the Roundwood Reservoir up the valley of the River Vartry, traversing the drainage area of the water supply, and passing by the Rocky Valley at the foot of the Sugarloaf Mountain. The Rock Boring Machine was seen at work in the Roundwood Tunnel; and the Members were handsomely entertained at the Roundwood Reservoir by Sir John Gray, M.P., the chairman of the Water Works Committee of the Corporation, and Mr. John Jameson, the deputy chairman.

On Friday, 4th August, an Excursion was made by the Members from Dublin by special free train, granted by the Great Southern and Western Railway Company, to visit the Derrylea Peat Works, near Portarlington, where the several processes of harrowing the peat bog, collecting and drying the peat mull, and compressing it in the peat presses into the circular discs were shown in operation by the managing director, Mr. Charles Hodgson, together with the employment of the compressed peat fuel for melting iron in the foundry. The Members were hospitably entertained by the Peat Company at the works.

On Saturday, 5th August, an Excursion was made by the Members from Dublin by free train, granted by the Dublin Wicklow and Wexford Railway Company, to visit the Connorree Copper and Sulphur Mines in the Vale of Avoca, under the guidance of the chairman, Dr. Waller, where the mining works and large adit were seen, and the process was shown of precipitation of copper in water upon iron. The Members were hospitably entertained at the works by the directors and officers of the Mining Company.

PROCEEDINGS.

2 NOVEMBER, 1865.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 2nd November, 1865; HENRY MAUDSLAY, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

JOSEPH WHITWORTH, . . .	Manchester.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

JOHN ANDERSON, ...	Woolwich.
CHARLES F. BEYER, ...	Manchester.
FREDERICK J. BRAMWELL, . .	London.
WILLIAM CLAY, ...	Liverpool.
EDWARD A. COWPER, . . .	London.
ROBERT HAWTHORN, ...	Newcastle-on-Tyne.
SAMPSON LLOYD, ...	Wednesbury.
HENRY MAUDSLAY, ...	London.
JOHN RAMSBOTTOM, . . .	Crewe.
C. WILLIAM SIEMENS, . . .	London.

COUNCIL.

(Five of the number to be elected.)

Alexander Allan,	Perth.
Charles Edwards Amos,	London.
Peter D. Bennett,	Westbromwich.
John Fernie,	Leeds.
Sir Charles Fox,	London.
Thomas Hawksley,	London.
Edward Humphrys,	London.
James Kitson,	Leeds.
Walter May,	Birmingham.
John R. Ravenhill,	London.
John Robinson,	Manchester.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Charles C. Beardshaw,	Sheffield.
John Bell,	Manchester.
John Cartwright,	Birmingham.
Matthew Curtis,	Manchester.
Benjamin Davies,	Chorley.
Henry Dircks,	London.
Robert Dyson,	Rotherham.
John McFarlane Gray,	Liverpool.
William Harrison,	Blackburn.
William Smith Longridge,	Ambergate.
John Maylor,	Rio de Janeiro.
William Pratchitt,	Carlisle.
Robert Robey,	Lincoln.
Christer Peter Sandberg,	Stockholm.
Edward Scott,	Manchester.
William Sellers,	Philadelphia, U. S.

JOHN TICKLE, ...	Westbromwich.
EDWARD TOOMEY, ...	Dublin.
JOHN JAMES TROW, ...	Wednesbury.
ALBERT VICKERS, ...	Sheffield.
WILLIAM WAINWRIGHT, . . .	Worcester.
JAMES EDWARDS WILSON, . .	London.
CLIFFORD ETCHES WINBY, . . .	Cardiff.

HONORARY MEMBERS.

FREDERICK BARKER, . . .	Leeds.
DAVID PARRY, ...	Leeds.
JOSEPH WHITLEY, . . .	Leeds.

The CHAIRMAN announced that an Honorary Life Membership in the Institution had been conferred by the Council, in accordance with the power given by the rules, upon Dr. Downing, Professor of Engineering in the University of Dublin, as a mark of their feeling of the great obligation to him for the important and valuable aid rendered by him on the occasion of the Dublin Meeting of the Institution, as well as in acknowledgment of his contributions to Engineering Science.

The following paper was then read:—

ON AN IMPROVED SAFETY VALVE FOR STEAM ENGINE BOILERS.

By Mr. WILLIAM NAYLOR, of London.

The subject of this paper is an improvement in the construction of the Safety Valves at present in use on locomotive marine and stationary engine boilers, for the purpose of preventing the pressure of the steam whilst blowing off through the safety valve from rising beyond the limit to which the valve is adjusted. This rise of pressure during blowing off is found to take place to a greater or less extent in all steam boilers with the ordinary safety valves, including locomotive marine and stationary boilers; but it occurs especially with locomotive boilers, where the safety valves are pressed down by levers with spring balances at the extremity, and the rising of the valve in blowing off causes a lifting of the lever and a considerable extra extension of the spring balance and consequent increase of pressure upon the valve.

From experiments made by the writer with locomotive boilers, he believes that a clear available opening of 7-10ths of a square inch will allow the steam to escape as fast as it can be generated in a large locomotive boiler at a pressure of 120 lbs. per square inch, when the engine is not consuming steam by running, and with the help of a steam jet in the chimney. Taking the theoretical velocity of steam at that pressure issuing into the atmosphere as 1900 feet per second, the practical velocity of the issuing steam, allowing for its friction in passing the safety valve and the resistance of the atmosphere into which it has to flow, may be assumed at 70 per cent. of this amount or 1330 feet per second. This velocity with the above-named opening of 7-10ths of a square inch gives a discharge of 11,172 cubic inches of steam passing off per second. Taking the

relative volume of steam to water at that pressure as 203 times, this is equivalent to an evaporation of about 12 gallons of water per minute (11·94); or a consumption of about 8 cwts. (7·99) of coal per hour, taking the evaporative duty at 8 lbs. of water per lb. of coal. This extent of evaporation and consumption the writer believes to be the maximum that could be attained under extreme circumstances in locomotive boilers.

The present large locomotive boilers are made some with two safety valves of $3\frac{1}{2}$ inches diameter, some with two valves of 4 inches diameter, some with two of 5 inches diameter, and some engines are working with four valves of 3 inches diameter; the valves being loaded by spring balances through levers, or in some cases by a spring acting direct, without the intervention of a lever. When the spring balance and lever are used, the proportions of the lever are generally arranged so that 1 lb. pressure of the balance is equal to 1 lb. per square inch on the valve; and then the perpendicular lift of the valve in opening multiplied by the number of square inches in its area gives the distance that the outer end of the lever has to move to allow the required opening of the valve; and this lift of the lever end multiplied by the number of lbs. to the inch in the graduations of the spring balance gives the number of lbs. per square inch of additional load put upon the valve by the act of lifting, and the corresponding increase of pressure necessitated in the steam to admit of its escape through the opening of the valve, in addition to that required for overcoming the friction of the steam in passing the valve and the resistance to it in flowing into the atmosphere.

Taking the case of two valves of 5 inches diameter, giving a combined circumference of 31·4 inches, and say 30 lbs. to the inch as the graduation of the spring balances, with a ratio of leverage (or area of valve) of 19·63 to 1, a total area of discharge of 7-10ths square inch would require a lift of the valves of $\frac{0{\cdot}7}{31{\cdot}4}$ or ·0223 inch; but as the bearing faces of the valve and seat are not horizontal but inclined at 45°, a vertical lift of the valve equivalent to 1 square inch (0·99) annular area is required for giving a discharging area of 7-10ths square inch; and the total lift will therefore be ·032 inch. This gives an extension of the spring balance of ·032 × 19·63 or ·628

inch, causing an extra load upon the valve of ·628 × 30 or 18·8 lbs. per square inch in order to get the required opening for discharge of the steam. The result is therefore that, in order to give a sufficient area of opening for the discharge of all the steam that the boiler is capable of generating, the pressure must rise in the boiler about 19 lbs. per square inch above the intended limit of the working pressure, or the point at which the safety valves are adjusted to begin blowing off; and this action of increasing the total pressure upon the valve as the valve rises is inseparable from all arrangements in which the valve is pressed down by a spring acting either through a constant lever or direct upon the valve.

The improved Safety Valve forming the subject of the present paper has been designed by the writer for the purpose of removing this defect, by causing the spring that presses upon the valve to act not through a constant lever, but through one which varies in its effective length, diminishing in length as the valve rises in the same proportion that the tension of the spring is increased by the rising of the valve, so as to prevent any increase taking place in the total pressure upon the valve.

The improved valve is shown in Figs. 1 to 4, Plates 63 and 64, Fig. 1 being a vertical section, and Fig. 2 a sectional plan.

The safety valve A is only 2 inches diameter inside the seating, and is pressed down by the inverted spiral spring B acting upon the opposite end of the bent lever C, the effective length of lever being $2\frac{1}{2}$ inches at the valve and $1\frac{3}{4}$ inches at the spring. When the valve rises, the bearing point of the spring at the end of the lever, being inclined downwards at an angle of 35° from the vertical line D in Fig. 3, is deflected nearer to this vertical line by the lifting of the valve end, as shown by the dotted position in Fig. 3; and the result is that the effective leverage at which the spring acts is reduced to the extent required to compensate for the increased tension of the spring caused by the motion of the lever, so that the total pressure upon the valve remains unaltered. The centre E on which the lever works is a knife-edge, so as to prevent its action from being interfered with by friction from the heavy pressure upon

it, which is nearly double the pressure of the spring; and the connection of the spring to the lever at F is by a knife-edge also, Figs. 3 and 4, in order to give complete freedom of action to the whole. The spiral spring is made of $\frac{5}{8}$ inch round steel, and the pressure upon the valve is adjusted by screwing up the spring by the nut G, the highest pressure being limited by a solid collar upon the spindle. Any accident from failure of the spring is provided against by the lower end of the lever then coming in contact with the casing at H, Fig. 3, which prevents any risk of the valve becoming displaced.

This valve being only 2 inches diameter with a circumference of 6·28 inches, the height to which it must be lifted in order to give the same area of discharge as before, 7-10ths of a square inch, is $\frac{7}{6 \cdot 28}$ or ·159 inch; and the valve end of the lever being $2\frac{1}{2}$ inches long, this requires an angular movement of the lever of 3° 39′. The angle between the spring end of the lever and the vertical is consequently reduced from 35° to 31° 21′; and taking the horizontal distance $1\frac{3}{4}$ inches or 1·75 inches as the sine of the former angle, the sine of the latter angle will be 1·59 inches, making a shortening of ·16 inch in the leverage at which the spring acts. The difference between the cosines of these angles to the same radius, or ·106 inch, will be the extension of the spring produced by the same range of motion; and the area of the valve being 3·14 square inches, the total pressure of the spring to give a pressure upon the valve of 120 lbs. per inch will be 538 lbs. with the original leverage of 1·75 inches, and with the reduced leverage of 1·59 inches the total pressure required at the spring is then 593 lbs. Hence an increase of 55 lbs. in the total pressure of the spring has to be produced by the extension of ·106 inch in length caused by the motion of the lever, in order to maintain a constant pressure upon the valve; and this gives 519 lbs. per inch deflection for the strength of spring required for the purpose.

In practice the spring is adjusted so as to give a slightly reduced total pressure upon the valve when fully open, the pressure per square inch on the valve being made about 4 per cent. less when the valve is blowing off strongly than when the valve is shut; in

order to compensate for the effect of the friction of the large quantity of steam passing in that case through the narrow opening of the valve. It has been found by careful trials with this valve that, when the steam is blowing off very strongly, the pressure within the boiler exceeds the load upon the valve by about 5 per cent.; and therefore by proportioning it as above with 4 per cent. less pressure of the spring upon the valve when open than when closed, the occurrence of any sensible increase of pressure within the boiler beyond the limit at which the valve is set is completely prevented. At the same time it is found that the valve closes again after blowing off strongly, without allowing any sensible fall in the boiler pressure below that limit.

This improved valve therefore effectually provides for the prevention of any increase of pressure occurring under any circumstances in the boiler beyond the intended limit of pressure; and the one valve, although only 2 inches diameter, gives the full area for discharge of the steam obtained with the two large valves ordinarily used. The one valve may consequently be considered as fully equivalent in safety to the two ordinary valves, although it may be preferred still to adopt the precaution of employing two valves.

In the case of the two ordinary safety valves of 4 inches diameter, having a combined circumference of 25·1 inches, and a ratio of leverage of 12·57 to 1, a total increase of pressure of 15·0 lbs. per square inch will be caused in giving the required full area of opening of 7-10ths square inch for discharge. And with two valves of 3 inches diameter, having a combined circumference of 18·8 inches, and a ratio of leverage of 7·07 to 1, the total increase of pressure will be 11·3 lbs. per square inch.

It appears therefore that, with the ordinary construction of safety valves, the larger size of valves, instead of giving increased freedom to the discharge of the steam, are actually inferior in this respect to the smaller valves, the two 5 inch valves allowing an increase of pressure of 18·8 lbs. per inch during the escape of the steam, whilst the two 3 inch valves allow only 11·3 lbs. per inch

increase with the same discharge. This arises from the circumstance that the pressure required to hold down the valve increases as its area or as the square of its diameter, whilst its area for discharge increases only as its circumference or directly as its diameter. This result is also not altered in the cases where, instead of using a lever with a spring balance at the end, a large spiral spring is employed pressing direct upon the valve, or between two valves, the pressure of the spring and its motion being then the same as those of the valve, instead of the pressure of the spring being diminished and its motion increased both in the same ratio by the action of the lever.

The improved valve possesses an important advantage over most forms of the ordinary valves, from the circumstance that it is quite impossible for the valve to be tampered with by the enginedriver so as to increase the pressure beyond the intended limit; and in the writer's personal knowledge the frequency of this occurrence with ordinary valves is much greater than is generally supposed.

One cause of extra pressure in locomotive boilers occurs when an engine is proceeding with a train, with the steam well up and a good fire, and it is suddenly checked by a danger signal being exhibited, and the engine has to be reversed. In such a case, whilst the fire is generating steam vigorously, the cylinders instead of using it are converted into air pumps, pumping air into the boiler at every stroke. The steam generated must all pass off by the safety valves, and the pressure often rises considerably above the limit at which they are adjusted.

When an engine is taking a heavy load up an incline slowly, the steam blowing off strongly, as much as 40 lbs. excess of pressure has occurred within the writer's experience, without the safety valves being interfered with. The writer has also known the case occur of a large goods engine coming to a stand on an incline from want of power, although the steam was blowing off very strongly; and the driver being afraid to go back from fear of a collision, has secured the valves against blowing off, by pegging down the levers

in the slots through which they passed in the weatherboard. The regular working pressure was 120 lbs., but the steam got up to 180 lbs. per inch by the pressure gauge, and the engine was then able to take the train to the top of the incline.

Another source of risk of extra pressure is when an engine is having the steam got up in the engine shed, and to hasten it the steam jet has been put on and left on while the fire-lighter is gone to look after other engines. From a number of experiments the author has ascertained that, if the jet be left full on for six minutes after the steam begins to blow off, there will be an excess of pressure in the boiler of at least 30 lbs. per square inch over what the safety valves on the ordinary construction are loaded at.

In the case of marine boilers it is required by the government regulations that there shall be at least one safety valve upon each boiler loaded direct by weights, and that the area of this valve shall be one circular inch for every horse power nominal; so that a boiler supplying steam equal to 100 horse power requires a safety valve 10 inches diameter. But although these valves are loaded by direct weights, the pressure in the boiler will necessarily exceed the load on the valve when the steam is blowing off in great force, which is liable to occur occasionally when the engines are stopped, from neglect in not easing the pressure at that time. There is however a serious defect in this mode of loading safety valves on marine boilers, from the circumstance that when the vessel rolls the pressure of the weight is diminished; and if it rolls to the extent of 45° there will not be more than 70 per cent. of the full load upon the valves at that moment, and consequently there will be a loss of power when the greatest power may be required. Moreover the water in the boiler is subjected to violent commotion by the repeated starts of ebullition from the pressure being suddenly reduced by the lifting of the safety valve; and this commotion is not at all times stopped by the closing of the valve, but produces priming in the cylinders. With the improved valve however the full pressure would be preserved steadily in the boilers, with any extent of rolling of the vessel.

On the boiler of a stationary engine a comparative trial has been made of one of these valves of only $1\frac{9}{16}$ inch diameter, and two other ordinary valves of $3\frac{3}{8}$ inches diameter, loaded one with dead weights and the other with a lever and spring balance, all the valves being adjusted so as to begin blowing off at the same pressure. The engine was stopped and the firing of the boiler continued, and the steam generated had all to escape through the safety valves. The valve loaded by a lever and spring balance did not appear to increase in the amount of steam passing by it, and the valve loaded by dead weights increased in extent slightly; but the improved valve increased to a perfect roar, thereby telling its own tale as to which valve was carrying away the steam. When the damper was closed and the firedoor opened, all the valves ceased blowing off at the same time.

The number of boiler explosions that have occurred from over pressure show the necessity of some effective means being adopted to prevent that occurrence; and if a boiler be at all defective in construction or have become so after long use it is the more necessary that it should be provided with safety valves which will render it safe against any excess of pressure occurring beyond the amount required for working the engine. All surplus pressure put upon a boiler through the defect of the safety valves not being able to carry away the steam as fast as generated is tending to positive destruction without any advantage; and if the boiler has a sufficient margin of strength to resist such surplus pressure as it is subjected to with the ordinary arrangement of safety valve, the use of a valve that will maintain a uniform pressure would have the advantage of allowing an increased pressure to be regularly used in the engines.

Mr. NAYLOR exhibited specimens of the safety valve, and explained that in the case of valves constructed for marine boilers an india-rubber diaphragm was fixed across the bottom of the chamber containing the spring, as at II in the 5 inch marine safety valve

shown in Figs. 5 and 6, Plate 65, so as to protect the spring from the corrosive action of any salt water thrown out from the boiler with the steam in blowing off, in consequence of the rolling of the vessel. This provision was not necessary in the valves for locomotive or stationary boilers, because in these cases the steam blowing off from the valve passed direct up the funnel placed over the valve, and any water carried off along with the steam by priming was blown out through the funnel in the same way, so that neither steam nor water was found to get to the spring.

The CHAIRMAN enquired how many of the new valves were now in use, and where they were at work.

Mr. NAYLOR replied that there were now about forty of the valves in use, most of which were on locomotive boilers, principally upon the Great Northern Railway. In the first adoption of the new valve upon that line, the size of the valve seemed so extremely small, in comparison with the safety valves previously employed, that a special trial was made to test the sufficiency of the new valve. One of the new valves of 2 inches diameter was fixed on a locomotive boiler, and the two ordinary valves of 4½ inches diameter previously used were removed: the engine had a large firebox, and in order to increase the generation of steam an additional length of funnel was attached above the chimney, and a steam jet was added in the smokebox. By this means a very rapid generation of steam was obtained, producing a great blow-off at the valve; but it was found that even under these extreme circumstances the pressure in the boiler could not be raised to as much as 10 lbs. above the limit at which the valve was set to blow off. In a trial made with one of the new valves of 1⅛ inch diameter, the result had not been satisfactory, because the valve had not been made with lift enough in that particular case; but from experiments subsequently made he was satisfied that a valve of only that size was amply sufficient in practice for a locomotive boiler, when arranged so as to allow the full lift required to give the necessary area of opening for blowing off; and the principle of the bent lever afforded the means of obtaining any amount of lift, without increasing the pressure upon the valve by the extension of the spring.

Mr. F. J. BRAMWELL thought the new safety valve was a very ingenious practical contrivance for getting over the defects of the ordinary construction of safety valves, and allowing the steam to blow off in any quantity with complete freedom at the intended limit of pressure. The defects in the principle of ordinary safety valves acted on by spring balances arose from two causes, the first being the extra pressure put upon the valve in blowing off, owing to the extension of the spring and the additional force consequently exerted by it; and although theoretically this extra pressure might be reduced to any extent by using a spring of greater length and consequently greater elasticity so as to give less increase of pressure with the same extent of stretching, yet in practice very little improvement could be effected in this way, as the total length of spring that could be employed was limited by practical considerations of convenience; and in the case of locomotive boilers it was not practicable to employ springs having much more elasticity than those at present generally used, which gave a force of not less than 20 lbs. per inch of extension. The second defect attendant upon ordinary safety valves arose from the circumstance that, at the time of blowing off, the pressure of the steam in the immediate neighbourhood of the aperture of the valve was reduced by the rapidity of the motion of the escaping steam; and consequently, in order that the valve might be held open for blowing off at the intended limit of pressure, it was necessary that the steam pressure within the rest of the boiler should have risen considerably above that limit, in order to keep the reduced pressure at the aperture of the valve up to that limit. Both of these defects in ordinary safety valves were completely met by the principle of construction of the new valve, in which the adoption of the bent lever not only allowed of the valve being lifted to the full extent without any increase of pressure being put upon it by the extension of the spring, but also afforded the means of actually diminishing the load upon the valve in lifting, to any extent that might be found necessary to compensate for the diminished pressure of steam at the aperture in blowing off. The principle of the bent lever thus caused the safety valve to blow off with certainty at the intended limit of pressure, without allowing the

steam in the boiler under any circumstances to rise beyond that limit by more than the small fixed percentage determined by the original adjustment in the proportions of the lever and strength of the spring.

Mr. NAYLOR remarked that the rise of pressure in blowing off with ordinary safety valves was also partly due to the resistance offered by the atmosphere to the escape of the issuing steam; and he thought the amount of this resistance was considerably greater than it was generally believed to be. For it was evident that in the case of a safety valve loaded by a dead weight instead of by a spring, if there were no resistance offered by the atmosphere to the escape of the steam, the steam would blow off with perfect freedom and the pressure would never rise above the intended limit, since the valve would lift to any required extent without the load upon it being thereby increased. But in practice it was found that this was not the case; for with an ordinary safety valve of 5 inches diameter loaded by a dead weight upon a boiler 25 feet long he had found that there was as much as 8 to 10 per cent. increase of pressure beyond the limit at which the valve was set to blow off; and he believed this was due to the resistance met with by the steam in issuing into the atmosphere.

Mr. F. J. BRAMWELL did not think the resistance offered by the atmosphere to the issuing steam was by any means so great as to account for an increase of pressure of 8 to 10 per cent. beyond the intended limit; but he considered this increase of pressure in blowing off was almost entirely due to the circumstance which he had previously mentioned, the velocity of the escaping steam causing the pressure to be so much reduced in the immediate neighbourhood of the valve, that in order to maintain the pressure at the valve up to the intended limit it was necessary for the pressure in the rest of the boiler to rise considerably above that limit. In accordance with this view of the question a construction of safety valve had been employed upon some boilers, having a slide valve worked by a piston; and the piston being acted upon by the steam pressure inside the boiler, at some distance from the aperture of the slide obtained, opened the slide at the intended limit of pressure and kept it the valve open without requiring the pressure to exceed the limit.

The CHAIRMAN enquired what was the cost of the new safety valves, in comparison with ordinary safety valves having levers and spring balances.

Mr. NAYLOR replied that the difference of cost of the new safety valves as compared with the ordinary valves was very little. The two new valves exhibited were each $2\frac{1}{2}$ inches diameter and were intended for locomotive boilers: the one with brass funnel and brass chamber for containing the spring cost £10 10*s.*, and the other made of iron with gunmetal valve and valve-seat cost £9. The new valves were much lighter than the ordinary valves of larger size, used for the same situations, with their levers and spring balances.

Mr. F. J. CANNELL thought the new safety valve was of very great advantage for boilers in ironworks heated by the puddling furnaces, where it constantly occurred that the steam was suddenly shut off from the engine while the furnaces required to be kept in full work; and in such cases it was of the utmost importance to have the means of blowing off through the safety valve the whole of the steam that the boiler could generate. At the Old Park Iron Works, Wednesbury, they had had one of the new safety valves of 2 inches diameter at work for six months on one of the locomotives working at 85 lbs. pressure, and it had given complete satisfaction; the engine had often stood still for $\frac{3}{4}$ hour with a full fire, and the steam had been so effectually carried off by the safety valve that the pressure in the boiler had not risen 1 lb. above the limit of 85 lbs. at which the valve was fixed to blow off; whereas in other boilers having ordinary safety valves with levers and spring balances the pressure rose 15 or 16 lbs. above that limit under similar circumstances. He had paid great attention to the working of the new valve, and was satisfied that it effectually prevented any rise of pressure in the boiler above the fixed limit.

Mr. W. FORD SMITH remarked that, on one occasion of taking to pieces for repairs an ordinary locomotive safety valve with lever and spring balance, he had found that the centre pin of the lever, having been carefully fitted in the first instance, had become rusted so tightly in the eye that it required an additional force of probably 60 to 80 lbs. at the end of the lever to lift it; and he was therefore

glad to see that pins were done away with in the new safety valve, a simple knife-edge bearing alone being employed as the fulcrum for the bent lever. He enquired whether the valve was guided in lifting by a centre spindle inside the boiler, because he had found that mode of guiding was also liable to the objection of the spindle becoming corroded in the guide, and he had seen safety valve spindles so encrusted in the guides that it was impossible for the valve to lift at all.

Mr. NAYLOR explained that in the new safety valve the valve itself was guided by three wings cast upon it, and not by a spindle; it was then not liable to become stuck by corrosion, and the only objection experienced in guiding by wings was when the valve seating was composed of a brass bush let into an iron seat, in which case the brass bush being unable to expand freely outwards became tightened upon the valve and caused the wings to bind in the seating, so that the valve could not lift. In the new valves however the seating was always made entirely of brass, so that there was no tendency to nip the wings of the valve in expanding.

In reference to the knife-edge bearing of the bent lever, the use of the knife-edge was very advantageous in reducing the extent of the bearing surface and thereby getting rid of the friction inevitably attending a round pin. The square centre pin forming the knife-edge bearing was fixed in the valve casing, so that it could not turn in its place; and the width of the bent lever was sufficient to ensure the knife-edge bearing holding it steady from any lateral twist in working.

A point of great practical importance in the new safety valve was the impossibility of tampering with the valve, as there was no external projecting lever which could be pegged down in its slot holes or loaded with additional weight; but the valve was entirely boxed up, and could not be got at by the enginedriver in any way.

Mr. J. TOMLINSON observed that it could only be owing to bad management if the levers of ordinary safety valves became rusted in their bearings, and he had found it necessary to have all locomotive safety valves taken to pieces regularly once every three months for examination and cleaning; and if the same plan were

carried out in other cases there would be no danger of the valve becoming corroded fast. In the new safety valve he thought there appeared a possibility of dirt getting into the closed part of the valve casing in which the bent lever worked, and so causing it to stick fast; and he enquired whether any difficulty had been experienced with the new valve in this respect. He asked also whether the fact of slightly relieving the load upon the valve in blowing off did not cause the steam pressure in the boiler to fall below the intended limit before the valve could be closed again by the spring. In the case of a locomotive boiler working with 120 lbs. steam, he should expect that the pressure would have to fall 6 or 7 lbs. below the limit before the valve would close again after blowing off.

Mr. NAYLOR replied that the pressure of steam in the boiler did not fall below the limit in blowing off, because as the violence of the blowing off subsided the valve gradually closed; and the spring and bent lever were so adjusted that the valve shut again exactly at the fixed limit of pressure. It was of course possible by altering the adjustment of the bent lever to relieve the load off the valve to such an extent when lifted, that it should not close again until the pressure had fallen to a given percentage below the limit; but in practice this had not been found desirable.

In regard to the lever becoming obstructed by dirt getting into the valve, this had not been found to occur with any of the valves yet in use; and he thought any dirt getting in at the funnel of the valve would be blown out again by the steam in blowing off. There was no reason to apprehend that the knife-edge bearing could become stuck fast by dirt, as it could not be made a tight fit like a centre pin; and the extent of bearing surface was so small that there was no room for particles of dust or dirt to collect in sufficient quantity to obstruct the free action of the valve.

Mr. F. W. WEBB remarked that the only way in which there appeared any possibility of tampering with the new valve was by driving a plug in at the top of the funnel over the valve, to interfere with its opening; or by dropping in a heavy weight upon the valve to increase the load upon it; and so much ingenuity had been

displayed by enginedrivers in tampering with previous safety valves, that it was very desirable to provide against any such attempts with the new valve.

Mr. NAYLOR said it was proposed to fix a cover of strong wire gauze at the top of the funnel over the valve, to prevent the possibility of tampering with it in any such manner as had been suggested.

The CHAIRMAN proposed a vote of thanks to Mr. Naylor for his paper, which was passed.

The following paper was then read:—

ON AN IMPROVED METHOD OF TAKING OFF THE WASTE GAS FROM OPEN-TOPPED BLAST FURNACES.

By Mr. GEORGE ADDENBROOKE, of Darlaston.

The utilisation of the Waste Gas from Blast Furnaces has now become not only an accomplished fact but a great commercial success, and consequently an important part of furnace management. This gas, or rather mixture of gases, issues in large quantities from all the interstices between the last charge of materials in the furnace throat; and it passes off with such rapidity as to prevent a sufficient mixture of air taking place to render it inflammable until it has risen to some little height above the top of the materials in the furnace mouth. As soon however as this mixture of air takes place, a very considerable portion of the gas is consumed, in the case of the ordinary open-topped furnaces that do not utilise the waste gas. This combustion develops a great amount of heat; and the question therefore arises, how can the waste gas be made further useful, without in any way injuring the yield, the working of the furnace, or the quality of the iron made; for if any injury were occasioned in either of the above respects by taking off the waste gas, the utilisation of the gas ought certainly not to be attempted. It is evident that there must always be an escape of surplus gas from the top of the materials in the furnace throat, from the consideration that the heat in the lower part of the furnace distils off the gas from the fuel in the upper part; and this gas, not meeting with a supply of oxygen inside the furnace, passes up unconsumed to the furnace mouth, where upon mixing with the external air it burns away to waste, unless taken off previously in order to be usefully burnt elsewhere.

The utilisation of the waste gas has been extensively carried out in two different modes, each capable of being applied and worked in several different ways. The one mode is known as the Close-Top system, and the other as the Open-Top system. Till the last few years however the writer believes that in no case was the waste gas successfully utilised in Staffordshire, though this had been effected a good many years previously in some other districts. The chief reasons for this continued waste of the gas in Staffordshire may be found in the cheapness of engine fuel, causing the mistaken idea to be entertained that it was cheaper to burn the slack under the boilers than to go to the expense of saving an article which would not be saleable; and also in the great dislike that all connected with the working of furnaces have to any considerable change in system.

The writer's attention was particularly called to the subject of utilising the waste gas from blast furnaces about five years ago, when he was engaged with others in examining the subject, and visited for the purpose many works where the utilisation was carried on at one or more of the furnaces. The decided opinion then arrived at was that the waste gas ought certainly to be utilised, and for the following reasons:—namely, that a furnace would work to better yield where the gas was utilised, and with greater regularity as to the quality of iron made; and that there would be a very considerable saving in repairs to hot-blast stoves and boilers by heating these with the waste gas, together with greater regularity in the heat and pressure of the blast, because of a more even temperature being maintained under the boilers and in the stoves; while there would also be a considerable saving in wages, and the men would be made more regular in charging the furnace.

The principle upon which the waste gas is taken off in the case of the close-topped furnaces is that, by keeping the furnace top closed, the gas must necessarily pass away through any openings which are made for its escape, and may thus be made to travel even to a distance of more than a quarter of a mile from the furnace, as is done at the Dowlais Iron Works. In the open-topped furnaces the idea is that, after the gas has done very nearly all its work in the

furnace, on arriving within about 5 feet of the top of the materials in the furnace mouth the greater part can be drawn off from the furnace by applying a mild suction, and employed to advantage for heating purposes elsewhere; at the same time, as no considerable amount of force is used for drawing off the gas, either by the suction of a chimney or otherwise, all surplus gas generated in the furnace beyond the amount drawn off escapes at the open top of the furnace, by passing up through an average of 3½ feet depth of charged materials above the point of taking off the gas.

The open-topped plans of taking off the waste gas may here be divided into two classes:—those taking off the gas at a less depth than 5 feet below the top of the materials in the furnace throat; and those taking it off below that level. In the former the gas is taken off with due regard to the effect on the yield and working of the furnace; while in the latter the utilisation of the gas is made the chief object.

In order to carry out the utilisation of the gas without risk of interfering with the successful working of the furnace, it is of very great consequence not to take off the whole of the gas, but to leave a certain portion always to escape at the furnace mouth, so that it may continue the process of preparing the newly charged materials, and begin to dry and warm them immediately upon their being charged, and also prevent any downward current of air taking place from the furnace top. Such a downward current of air must necessarily take place frequently, where the whole of the gas is drawn off; as the chimney power requisite for this purpose would be quite sufficient to draw down the air through the average depth of 3½ feet of materials in the furnace throat above the gas openings, at any time when there was not an ample supply of gas to be drawn off. The result would then be that where the ascending gas and the descending air met in the furnace a bright flame would be produced, which taking place amongst the fuel must occasion a very serious loss, by causing combustion of the fuel before it reaches the part of the furnace where its combustion is useful; and it appears doubtful whether fuel thus once lighted would not continue

smouldering the whole of the way down in the furnace. On the other hand if the fuel is properly covered in the upper part of the furnace by a sufficient depth of materials, so as to be protected from the air, the writer doubts whether it will begin to burn till it reaches the zone of fusion, where it then changes from a mere highly heated state to one of active combustion caused by the presence of air supplied from the tuyeres. The writer believes that in the fact of covering up the fuel, without ignition being allowed to take place, lies one of the chief sources of saving in the yield of the fuel; and he considers that it is this alone in the close-topped furnace, which to a very great extent makes up for the loss of yield of fuel that must inevitably result from the use of the close-topped system with its consequent back pressure. This saving however is more than counterbalanced by the fact that neither drying nor warming nor any other preparation of the materials can be carried on in the close-topped furnace except by the heat of the gas coming up from below.

Were it not for the back pressure produced in the furnace by a closed top, this system would doubtless work to a much better yield than the open top; but the entire prevention by the closed top of any drying or warming of the materials taking place until they have descended some distance within the furnace is a serious objection in the writer's opinion to the close-topped plan; whilst on the other hand in a well worked open-topped furnace the preparation of the materials begins at once upon their being charged. Moreover there is no way of so regulating the "driving" of a furnace or rate of descent of the materials in the interior as that in every hour the furnace shall take the same quantity of blast; but whenever the steam pressure happens to rise above the average, causing the engine to force more blast into the furnace, or whenever the materials happen to lie more open in the furnace or to be drier, an increased driving of the furnace will be occasioned, which will give an increased production of gas to pass off from the furnace. As this larger quantity of gas has in the close-topped furnace to pass off through the same openings which previously carried off a smaller quantity, the result must be an increase of the back pressure in the furnace;

whereas with an open top the surplus gas readily escapes at the mouth of the furnace, without producing any back pressure inside the furnace. Another objection to the closed top is that the pressure coming from the lower part of the furnace will carry off with it from the furnace more dust than would be drawn off by suction.

The desideratum in the utilisation of the blast furnace waste gas appears therefore to the writer to be an open top where the fuel can be buried or covered, without its being ignited to any material extent either by the escaping gas, or worse still by the gas being drawn off so completely from the furnace throat that air is drawn down also through the materials, causing a hidden fire to be raging beneath the surface of the materials while everything seems to be going on well. The writer has indeed frequently seen the gas drawn off so completely that a man could walk inside the mouth of a large furnace while the blast was on; but experience shows that such a state of the furnace top is altogether wrong, and if ever it occurs the main gas valve ought at once to be closed sufficiently to ensure some gas passing off at the furnace top, in order to begin the preparation of the materials and prevent any downward current of air.

The level at which the gas is taken off from the furnace is in the writer's opinion a most important point, as in effect the working height of the furnace nearly terminates at the level where the gas is taken off. The most satisfactory working that the writer has known of a blast furnace has been where the gas was partially and not wholly taken off and at a depth of 4 ft. 6 ins. below the top of the materials. In one case that came under his experience, one of Darby's bells was used very successfully for a considerable time, taking off the gas at a depth of 4 ft. 6 ins. below the top; but when it became necessary to change it, the new bell was inserted to a depth of 5 ft. 6 ins., in order to give the fillers a little more range of level; this was however found to work so much less satisfactorily that it was altered back again to the original depth of 4 ft. 6 ins.

The very great sensitiveness of a furnace to the least lowering of its working height is undoubtedly the cause of more than one half of the mottled and white iron that is made where grey forge or forge iron was expected. The change is usually caused by delay in filling, most frequently at night, when the men often neglect their work and allow the furnace to drive, so that the surface of the materials is lowered a considerable distance; and the effect is then observed about three casts later by the production of mottled or white iron. The worst consequence of this neglect is that the furnace manager then finding white iron made probably alters the burden at once in order to correct the fault; and after charging it up to the next casting time with either less ore or more fuel, he probably finds this next cast all right, and therefore alters the burden back again; but in another cast or two comes the iron made from the lighter burden, rather too grey to suit the purposes it is wanted for. With a closed top there can be no check upon irregularity in filling, day or night, except by constantly watching the filling. But in an open-topped furnace where the gas is taken off through openings not lower than 5 feet below the top of the materials, if the filling were delayed more than half an hour, the greater portion of the gas would begin to escape at the furnace mouth instead of being drawn off through the gas openings, as the surface of the materials would be lowered nearly to the level of the gas openings. The fillers' neglect would then be detected by an increased flame from the furnace mouth, and by the supply of gas to the boilers and hot-blast stoves falling short; and they would be recalled to their duty by the risk of all coming to a standstill from stoppage of the blowing engine.

This great sensitiveness of blast furnaces as to being kept charged full appears to suggest strongly the doubt whether the Staffordshire furnaces are now as high as the fuel would allow of their being worked profitably; and whether a gain of yield would not be found to result from raising the furnaces. The present height of from 40 to 50 feet in Staffordshire has been increased in the Cleveland district up to 80 feet and more, and it is considered the limit of height has not yet been arrived at in that district.

There is no doubt that the Staffordshire fuel would not stand any very considerable increase of height, on account of its friability; but it would at least be desirable to ascertain by trial whether some increase of height would not be beneficial.

The result of the previous enquiries in which the writer was engaged as to the best mode of utilising the waste gas from blast furnaces was the adoption of the open-topped plan with Darby's bell inserted in the neck of the furnace to a depth of 4 ft. 6 ins. below the surface of the materials; and the writer has much pleasure in acknowledging the good service rendered in connection with the South Staffordshire iron district by the introduction of this plan to notice in the valuable paper read upon the subject at a former meeting of the Institution five years ago, (see Proceedings Inst. M. E., 1860, page 251). This plan was applied to two furnaces at the writer's works at Darlaston; and in carrying it out the special points attended to were to provide a large gas main, a large chimney, and large flues to the chimney. For this purpose the gas mains were made 5 ft. diameter, the chimney 10 ft. diameter inside throughout with a height of 160 feet, and the main flues to the chimney very large, 5 ft. high to the crown of the arch and 4 ft. 6 ins. wide; and experience has shown that these dimensions are none too large.

The two furnaces continued at work on this system till September 1864, when the heavy cost of repairs and renewals with the consequent stoppages and loss in wages led the writer to design the plan to be described in the present paper, which is shown in Figs. 1 to 7, Plates 66 to 70. Fig. 1, Plate 66, is an outside elevation of the furnace to which this system is applied. Fig. 2, Plate 67, is a vertical section of the same furnace, showing the gas openings A A from the furnace into the neck flue B, and the gas branch pipe with stop-valve C for connecting or disconnecting this furnace from the range of gas main. Fig. 3, Plate 68, is a sectional plan of the furnace taken through the gas openings A A and neck flue B. Fig. 4, Plate 69, is an enlarged section of the furnace top; and Figs. 5, 6, and 7, Plate 70, show a

vertical section, outside elevation, and sectional plan, of one of the segmental boxes or gas openings.

These gas openings or boxes are made of cast iron, which material has been found to stand very well, and allows of the openings being made so wide that their combined area of passage is amply sufficient for the passage of the gas, without the depth of the opening being more than 15 inches; in consequence of which they do not require to be inserted lower than about 5 feet down, and still leave a fair height of 4 feet above them for variation in the level of the top of the materials charged. The boxes are cast very strong, as shown in Figs. 5 to 7, and the openings through them are made at such a slope that nothing except very light dust can be carried through them by the gas in regular working, unless it be a bit of material thrown over by one of the slight explosions that occasionally take place where any raw minerals are used in the furnace. The boxes are placed close together side by side, so as to form a continuous ring of openings round the furnace, as shown in the plan, Fig. 3, having the lower end of the slopes opening into the furnace and the upper end opening into the large external gas flue B, Fig. 4, which surrounds the neck of the furnace. These castings take the place of so many courses of lining bricks, and after they have been fixed the lining firebricks are continued above them to the top of the furnace. Considering their strength and situation, the castings appear likely to be almost permanent. As they stand flush with the face of the lining, the whole area of the throat of the furnace is left free for charging; and when the furnace is full and any portion of the gas passing off at the surface of the materials, no damage can be done to the openings or any part of the gas apparatus. In case of the top of the materials sinking below the gas openings, any damage is prevented by shutting the gas valve C at once, when the whole of the gas will be burnt at the mouth of the furnace, but without injury occurring to any part of the apparatus, as is unavoidably the case with the wrought iron gas main proceeding from a bell inserted in the top of the furnace.

The large gas flue B surrounding the neck of the furnace is lined with firebrick, and is 4 ft. 3 ins. high to the crown of the arch

by 3 ft. mean width. The outside of the furnace from a little below the bottom of the flue upwards is cased with wrought iron plates, to which is fixed a light iron gallery D for the convenience of cleaning out the flue B. A series of openings E E are made in the outer side of the flue all round, as shown in the plan, Fig. 3, which are closed by pieces of boiler plate daubed with moistened fireclay and held in their places by crossbars and wedges; by means of these the whole of the neck flue can be cleaned out in a few minutes any time that the blast is off the furnace. The bottom of the flue is placed at a lower level than the bottom edge of the gas openings A A, Fig. 4, in order that the dust carried over with the gas may be allowed to accumulate in the flue, so long as it does not interfere with the gas openings, and it can be easily cleaned out when required. Experience of the working of this plan of furnace top proves that, from the increased area of the gas openings as compared with other plans, the gas does not pass nearly so rapidly out of the furnace, and consequently has not the power to carry nearly so much dust into the flue. The sectional plan Fig. 3 shows that there are fifteen gas openings A A round the neck of the furnace, 23½ inches wide and 11½ inches high on the square, each giving 270 square inches clear opening, making a total area of 4050 square inches for drawing off the gas; whereas the single central opening of the bell of 4 ft. 6 ins. diameter previously worked in the same furnace, which was as large a size as could be conveniently used, gave an area of only 2290 square inches for drawing off the gas, or only 56 per cent. of the area now obtained with the present neck openings. As the gas openings give a total area of 4050 square inches for the passage of the gas, while the descending gas main supplied by them being 4 ft. 6 ins. diameter has an area of only 2290 square inches, the velocity of the current of gas through the openings is necessarily only half what it would be where a bell or centre opening is used for drawing off the gas, as in the latter case the gas opening to the furnace cannot be made of larger area than the descending gas main of 4 ft. 6 ins. diameter.

The furnace first put to work on this plan by the writer was started in September 1864; and as fear had been frequently

expressed previously, that if the gas was taken off from the outside of the furnace instead of from the centre the working of the furnace would necessarily be injured, the work was not done at all substantially at first, but merely with cast iron plates 2 inches thick to form the gas openings, by way of trial. This fear however of drawing off the gas from the outside of the furnace within a reasonable distance of the top, instead of from the centre, appears when fairly looked into to be unfounded. For the gas has to ascend a height of about 40 feet through a furnace filled with considerable sized masses of solid fuel, ironstone, and limestone; and therefore becomes broken up into innumerable separate columns, each of which is again turned in different directions as soon as it meets with another solid obstruction.

Notwithstanding the temporary kind of construction that was adopted for trial in the first furnace, the gas openings made with only 2 inch cast iron plates lasted more than a year, and stood some of the severest treatment that a furnace top can be exposed to, in consequence of a sort of fuel being tried at one time which proved a total failure, and with which the furnace was unable to drive at all; and consequently for two days the whole throat was at a red heat. It was expected that when the furnace did drive below where the openings had been they would be found to have given way. They had not however completely given way in any instance, and though the plates were very much bent they remained at work a great part of a year afterwards. Their standing so well is to be attributed to their position, in the outside of the furnace instead of in the centre; and also to the effect caused by closing the valve on the top of the descending gas main, so that no gas or flame could then pass outwards through the openings, as there was no longer any current to draw the heat through the openings. Had a bell been at work in the centre of the furnace top in this instance, the only way to save it would have been to disconnect it and lift it out entirely; but this could not have been done till the materials in the furnace throat had lowered themselves below the mouth of the bell.

As the gas openings are now cast, as shown in Figs. 5, 6, and 7, it is anticipated they will stand for many years. The repairs also

seem to be quite unimportant, for when required it will only be necessary to change the old set of openings or castings for a new set, and the iron in the set taken out will be nearly equal in weight to that put in.

The advantages of this plan of taking off the gas may be summed up as follows.

The whole height of the furnace throat is left free for charging, which is equivalent to giving additional height to the furnace in comparison with other modes of taking off the gas.

The top of the gas openings being 4 feet below the top of the furnace, as long as the materials are kept charged up to within 3 ft. 6 ins. of the furnace top no damage can be done by flame to the gas apparatus, except by carelessly allowing the chimney draught to be so strong as to take off more than all the gas and consequently draw in some air from the furnace top.

There is no wear and tear from the shocks of the successive barrow loads of material charged, which do so much damage to a cylinder carried upon brick arches or a bell suspended in the furnace throat.

The whole of the gas apparatus is of simpler construction; and being all placed below the charging platform, it is much cooler and more free for the men to get at. From the large area of the gas openings and neck flue, which allows the dust to be for the most part deposited in the neck flue, the gas apparatus is less liable to become foul; and this neck flue can be cleaned with the greatest ease whenever required.

From the great strength of the castings forming the gas openings and their advantageous situation, next to no repairs are required, and there are consequently fewer stoppages, and an increased make of iron is the result.

There is also the convenience of being able at any time to burn any portion or even the whole of the gas at the furnace mouth without doing any damage to the gas apparatus.

The experience of the working of this plan of taking off the waste gas at the writer's furnaces is very satisfactory as to yield and greater regularity in make of iron, in consequence of there being

fewer stoppages; whence also there is a great saving of wages. By this plan the desideratum previously mentioned may be very nearly if not quite attained; namely an open-topped furnace where under no circumstances can there be back pressure or the trouble of lifting a charging cone. The ring of openings of 15 inches height, at a depth of not more than 4 feet from the furnace top to the top of the openings, are found able to take off just as much gas as is desired, by opening or closing the gas valve and so only permitting enough gas to escape at the top of the materials to warm and dry them without firing the fuel in the furnace top to any material extent.

In many previous instances the gas has indeed been taken off through the sides of a furnace and into flues in the brickwork of the furnace; but then it has been taken off at so great a depth that its withdrawal from the furnace at so early a period must be injurious; and the openings have been made 3 or 4 feet deep, thereby greatly weakening the structure of the furnace. It is evident that by taking off the gas lower down in a furnace it is taken off under a pressure sufficient to force its way through the materials above that depth, and by this means the gas may be drawn off without so powerful a chimney: but by so doing the working height of the furnace is in effect greatly reduced; and experience shows that in the Staffordshire furnaces at least there is great value in every foot of height that can be worked, while probably a trial would show something valuable in an additional 6 feet of height or more.

Mr. N. Neal Solly said that he fully concurred with the views advanced in the paper as to the advantages of open-topped blast furnaces over those working with a closed top; and having had several years' experience at the Willenhall Furnaces in taking off the waste gas from open-topped furnaces, by means of a bell suspended in the centre of the furnace throat, he was satisfied that the plan described in the present paper was a great improvement, and decidedly superior to the other modes of taking off the gas, as

the suspended bell was liable to frequent accidents. He enquired whether the supply of gas obtained by this means was always found as large and as regular as when taken off by the bell previously used, and whether it had always done the work as satisfactorily in the boilers and hot-blast stoves.

Mr. ADDENBROOKE replied that this plan was found even more effective than the bell suspended in the furnace throat; indeed the ring of openings round the neck of the furnace were capable of taking off the whole quantity of gas that the furnace yielded. By the aid of the powerful chimney draught he had seen the gas so completely drawn off that a man had been able to walk across the top of the materials in the furnace throat, whilst the furnace was working at the rate of 220 tons per week: but in this case there must have been air drawn in through the top of the materials by the draught being unnecessarily strong, which would cause combustion to take place immediately below the surface, where it was very undesirable; and accordingly orders were given to the men that, whenever the flame disappeared entirely at the furnace mouth, the gas valve was to be partially closed until a slight flame appeared again, so as to make sure that no air was being drawn down through the furnace top.

Mr. P. A. MILLWARD, engineer at the Rough Hay Iron Works, Darlaston, said that the gas taken off from the furnaces by the system described in the paper had been found to do its work in the boilers and hot-blast stoves quite as well as when taken off by the bell previously used; and the present plan not only gave the means of drawing off much more gas than was required for heating purposes, but also admitted of taking off the whole of the waste gas from the furnace, though that was more than it was desirable to accomplish.

Mr. J. E. SWINDELL enquired whether the heating of the boilers and hot-blast stoves was not interfered with whenever the gas valve was closed on the occasion of the flame disappearing at the furnace mouth.

Mr. ADDENBROOKE explained that the gas valve was never shut entirely; but whenever the flame disappeared at the furnace top

the valve was partially closed to a sufficient extent to cause a portion of the gas to pass out at the furnace mouth and restore the flame. Even when the gas valve was partially closed however there was an abundant supply of gas for heating purposes; for the furnace produced always more gas than would be required even with the oldest and least economical forms of boilers. The boilers used at the Rough Hay Iron Works were plain cylindrical boilers without any flues, and they supplied steam to the blast engine, and to the engine employed in the fitting shops and for working the wood-sawing machinery and raising the materials for filling the blast furnaces; and the whole of the heating was done by the waste gas, without the use of any other firing. An important advantage in the employment of the waste gas for this purpose had been that it had effected a very considerable saving in repairs both of boilers and hot-blast stoves; the boilers and stoves frequently worked for several weeks together without the firedoors being once opened, so that they were not subjected to the constant exposure to expansion and contraction by alternate heat and cold, and consequently the boiler plates and hot-blast pipes lasted much longer before requiring repairs than when heated by burning coal under them; there had indeed been scarcely any repairs required since the waste gas had been employed for heating.

Mr. J. E. SWINDELL thought the plan described in the paper was certainly a step in the right direction for taking off the waste gas from open-topped furnaces. In the case of close-topped furnaces, where the whole of the waste gas was taken off, he understood the supply of gas obtained was always found greater than was required for all the purposes to which it was applied; and therefore there seemed no reason to doubt that in the open-topped plan now described a sufficient quantity of gas might always be obtained from the furnace, while still leaving some to burn out at the open top of the furnace. He enquired whether the fuel employed in the furnaces described was all coke.

Mr. ADDENBROOKE replied that since the present plan of taking off the gas had been adopted the fuel employed in the furnaces had not been entirely coke, but a good deal of coal had been used also.

This had nothing to do however with the mode of taking off the gas, which was equally effective whether coal or coke was employed. In one respect this plan of taking off the gas was certainly invaluable in furnaces where coal was used, as compared with a bell suspended in the mouth of the furnace; for the flame burning out at the mouth of a furnace working with coal was so much hotter than with coke that the bell and the horizontal branch pipe leading from it became very highly heated, and were greatly injured by the flame; but in drawing off the gas by the neck openings below the surface of the materials, no part of the gas apparatus was exposed to the flame in the furnace mouth, and the whole of the flues and pipes were kept so cool that within a few feet of the neck flue the hand could be held upon the $\frac{1}{4}$ inch plates of which the gas main was composed. Moreover in the case of a bell suspended in the furnace mouth the area of the bell was no larger than that of the gas main, and therefore the full force of the chimney draught acted at the bell, causing a large quantity of dust to be drawn off with the gas; but in the present plan the area of the gas openings round the neck of the furnace was greater than that of the gas main, so that the gas came off quietly through the openings and carried over less dust with it; and the dust was then deposited in the neck flue instead of all passing down the gas main.

Mr. J. E. SWINDELL observed that mention had been made in the paper of a close-topped furnace at Dowlais, from which the gas was carried to a distance of a quarter of a mile before being consumed; and he enquired whether it could be conveyed to as great a distance if required in the mode now described of taking off from open-topped furnaces.

Mr. ADDENBROOKE replied that in the open-topped furnaces the gas could be taken to any distance, according to the power of the chimney draught, and with the advantage that the working of the furnace would not be affected by any back pressure, whatever might be the distance to which the gas was conveyed. With a more powerful chimney however the gas openings would have to be placed rather lower down in the furnace, so as to avoid drawing in air with the gas. In the case of the close-topped furnace at Dowlais that

had been named, a portion of the gas taken off was employed near the furnace for burning bricks and calcining ironstone; and the rest of the gas was then conveyed to a distance of about a quarter of a mile to heat the boilers of the forge and rolling mill; but the back pressure produced in the furnace top by forcing the gas along such a length of pipe amounted to $\frac{5}{16}$ inch of water, and he understood it was intended to employ a fan for drawing off the gas, so as to diminish this back pressure on the furnace.

Mr. W. HADEN enquired whether there would not be some difficulty in replacing the castings forming the gas openings round the neck of the furnace, whenever they required renewal; and whether it would not be advisable to make some provision for replacing them readily in the event of any mishap.

Mr. ADDENBROOKE replied that with the present strong construction of the castings forming the gas openings, of which a full size model was exhibited, it was not expected that there would be any considerable wear, and there was reason to expect they would last quite as long at least as the lining of the furnace; and as they merely took the place of a few courses of lining at the top of the furnace, they could readily be replaced if requisite at the time of renewing the lining. The durability of the castings would of course depend upon the care with which the furnace was worked, and if there were a flame through the gas openings it would necessarily cause destruction of the iron; but it must be borne in mind that when the working was properly managed, so that a flame was always kept burning out at the furnace top and the loading of the materials kept up to the proper height above the gas openings, the gas was drawn off through the openings without any flame, because no air was then drawn down from the top to produce flame below the surface of the materials; and consequently the castings were not exposed to injury from the passage of the gas through the openings. Even the first gas openings, constructed of only 2 inch cast iron plates, as a temporary expedient by way of making trial of the new plan, had continued satisfactorily in work for upwards of a year, notwithstanding the very severe test to which they were subjected within three months of being put in,

when the whole throat of the furnace had been at a red heat for two days; and the present castings were so much more massive that they were expected to prove much more durable. On the occasion of putting in the new castings in the second furnace to which the plan had been applied, which had been done about nine months ago, advantage had been taken of an opportunity when work was slack; and the blast being turned off, the furnace stood six days with the charge in it while the top was taken down sufficiently far to put in the new set of openings, after which the working was continued again without any inconvenience resulting from the stoppage. At present there had been only nine months' actual experience of the durability of the castings; they did not show any injury, and whenever they might require renewal, the cost of replacing them would not be serious, as the iron originally put in would be nearly all recovered in the old castings taken out.

The CHAIRMAN remarked that as the ring of gas openings round the neck of the furnace was composed of separate segmental castings, he presumed it would be practicable at any time to replace a single defective casting without much difficulty; and he enquired what was the weight of each of the castings, and whether they were placed contiguous to one another all round the circle, or whether there was anything interposed between the successive segments.

Mr. ADDENBROOKE replied that the castings weighed nearly 1 ton each, and were placed close together round the furnace throat without anything between them; and for taking out any one of the castings it would only be necessary to take down the furnace top immediately above that particular casting, so as to allow of lifting it out by a crane and putting in another casting in its place.

Mr. C. P. SANDBERG remarked that the utilisation of the waste gas from blast furnaces had been clearly proved to be beneficial, even where fuel was cheap; but the difficulties by which it was attended, namely irregularity in the working of the furnace, increased consumption of fuel per ton of iron produced, and liability to explosions, had to be carefully guarded against, otherwise the result would be a loss instead of a saving.

On the Continent and in Sweden the waste gas had been utilised for twenty to thirty years past. In Sweden Professor N. G. Sefstrom, of the School of Mines at Fahlun, had been the first to employ the gas for the calcining kilns and hot-blast stoves. The gas was taken off through an opening in the wall of the furnace about 5 feet below the top, and the furnace top was left open. The hot-blast stove was placed at the level of the furnace top; and the calcining kiln was also placed in a high position, in order that the gas might not have to be drawn down to a much lower level, which was to be avoided on account of the small pressure of the gas. In some places a vertical cylinder of nearly the same diameter as the furnace mouth was inserted in the top of the furnace, for taking off the gas from the top, thus obtaining a higher pressure; while the surplus gas was allowed to escape through the annular space between the cylinder and the furnace wall. This plan had been applied to charcoal furnaces with but little difficulty, so long as the gas was not required to be drawn down from the furnace top to a lower level; but considerable difficulties had arisen when the fireplace where the gas had to be burned was situated down at the level of the tuyeres, in which case the necessary power for drawing the gas down had not been obtained even with the assistance of an ordinary large chimney; and the result had been a greater consumption of fuel in the furnace instead of a saving. In order to ensure the gas being drawn down, it had been found advantageous to have a pressure of gas in the tube of not less than $\frac{1}{2}$ inch of water at the furnace top and 1-10th inch near the fireplace at the level of the tuyeres.

In conveying the gas through tubes from the furnace top to the fireplaces it was found better to have a positive pressure or plenum inside the tubes; so that the small openings for leakage round the valves, which could scarcely be avoided, might allow the gas to escape, instead of drawing air into the tubes. In the fireplace also the combustion was better effected when the gas was delivered there by pressure than when drawn down by means of a draught. It had also been found necessary to avoid the horizontal gas tube at the top of the furnace, because it was liable to become filled up with dust deposited there from the gas taken off; and it was desirable to

conduct the outer end of the gas tube into a water cistern, which acted both as a receptacle for dust and also as a safety valve.

In coke furnaces the means of obtaining the requisite pressure in the upper part of the furnace for forcing the gas down from the furnace top had generally been by working the furnace with a closed top; but in charcoal furnaces the charge itself acted as a sufficient cover to close the furnace top, the ore being crushed to a fine state; and in these furnaces therefore it was sufficient to lower the opening for the escape of the gas, while the furnace top was left open. The close-topped furnaces were worked in many localities in England and on the Continent, while the open-topped furnaces were employed in some parts of France, Germany, and Sweden; and in the Swedish furnaces charcoal was used exclusively. In the case of six open-topped charcoal furnaces in Sweden of which he had had the management from 1856 to 1860, the hot-blast stoves were removed from the top of the furnaces down to the level of the tuyeres, and the necessary pressure of the gas was obtained by lowering the gas opening down to 14 feet below the top, the height of the furnaces being 42 feet. No chimney was used in connection with the stoves, and no loss of fuel or other objection was caused by taking off the gas so low down in the furnace.

In the plan described in the paper for taking off the waste gas, the use of a chimney draught for drawing down the gas from the furnace top had been carried out to a much greater extent than he had ever seen successfully accomplished before, the gas openings being only 4 feet below the furnace top, which was left entirely open, and the gas being drawn down to the level of the tuyeres entirely by the force of the chimney draught. Such an arrangement appeared a retrograde movement in the principle of taking off the waste gas; but having had the pleasure of seeing the working of this plan at the Rough Hay Furnaces, he had found that it proved completely successful in practice. The supply of gas at the boilers appeared to be plentiful, and the combustion was well regulated; and the whole arrangement was well worthy the attention of every one connected with the working of blast furnaces. He thought however that with the gas openings situated at only 4 feet depth

below the open furnace top, and with such a large chimney for drawing off the gas, there would be need of special care to keep the furnaces at all times well filled and regular in the level of the charge; otherwise air would be drawn down from the top, and entering with the gas into the pipes would cause explosion. The reason assigned for placing the gas openings so near the top of the furnace was that the consumption of fuel had been found to be increased when the gas was taken off at a lower level; but in this respect the experience of the furnaces referred to in the paper differed from that of the Swedish charcoal furnaces, as well as the Continental coke furnaces, where the gas was taken off at a much greater depth below the top without increasing the consumption of fuel.

Mr. ADDENBROOKE observed that, though the use of a chimney for drawing off the gas from the blast furnace appeared to be little known in connection with the Swedish furnaces, it was by no means new in this country, having been employed previously for furnaces in Staffordshire, as well as in the Yorkshire and Welsh districts. The level at which the gas was drawn off from the furnace had been found in his own experience to be an all-important point; and he did not understand how this could have been found a matter of indifference in the Swedish furnaces.

As regarded the liability to explosion in taking off the gas by the mode described in the paper, he had not found there was any liability to explosion unless through gross carelessness and mismanagement. In Sweden he understood there had been several explosions, and nine or ten hot-blast stoves had been split by explosions; and he thought this was to be accounted for by the plan of taking off the gas, having a plenum of pressure to force the gas down from the furnace top, instead of a chimney draught to draw it down; so that, whenever the stoves were standing idle, there was a liability of some gas being still forced into them through the leakage of the valves; and as there was no draught to carry it off, this would hang in the top of the stoves and form an explosive mixture with the air, and then an explosion would ensue when a light was applied to it. But with the chimney draught as

employed at his own works, the regulations were that the draught was always to be put on the stoves before the gas was admitted, so that there was no opportunity for any explosive mixture to be formed; and he had accordingly had scarcely any accidents by explosion in the use of the waste gas for the boilers and hot-blast stoves.

Mr. JOHN JONES enquired whether in taking off the waste gas by the plan described in the paper the production of pig iron by the furnaces had been greater or less than before the gas was taken off.

Mr. ADDENBROOKE replied that the production of pig iron had certainly been found to be increased since the waste gas had been taken off, the make of each furnace having now got up to more than 200 tons per week, instead of the former make of only 150 or 160 tons per week. He did not consider however that the whole of this increase of make was to be attributed to taking off the waste gas, as he thought it was partly due to the use of the new gunmetal tuyeres, which had recently been adopted for blowing the furnaces, and which formed the subject of another paper at this meeting. Another advantage which had been experienced was that the quality of the iron made was very much more regular than before the gas was taken off from the furnaces.

The CHAIRMAN moved a vote of thanks to Mr. Addenbrooke for his paper, which was passed.

The following paper, communicated through Mr. Addenbrooke, was then read:—

DESCRIPTION OF A GUNMETAL TUYERE FOR BLAST FURNACES.

By Mr. N. NEAL SOLLY, of Willenhall.

For the Tuyeres of Blast Furnaces there are two distinct kinds of iron water tuyeres generally in use.

The first of these is the Cast Iron or Scotch tuyere, which is made of a coil of wrought iron tube imbedded in the sides of a hollow cone of cast iron, as shown in Figs. 1 and 2, Plate 71; each end of the coil projects from the back end of the cone, and through this coil the water for cooling the tuyere circulates, as shown by the arrows. This construction of tuyere is generally in use in Scotland, North Staffordshire, Cumberland, and parts of Wales, &c. A tuyere formed of a coil of wrought iron tube not imbedded in cast iron is also used in some places.

The second tuyere is the Wrought Iron or Staffordshire tuyere, which is shown in Figs. 3 and 4. It is forged out of boiler plate, and is made in the form of a truncated cone, the sides being hollow to allow of the circulation of water through them. The water enters from a pipe through a hole on the lower side of the outer end or back of the tuyere, and is discharged in a similar way from the upper side, as shown by the arrows.

In each description of tuyere the blast enters the furnace through a wrought iron nozzle pipe placed in the axis or centre of the conical tuyere. Although both these kinds of iron tuyeres are a great improvement upon the tuyeres that were used before the introduction of the hot blast, the chief objection to them consists in the fact, that after they have been at work a comparatively short time, which is very variable, being sometimes only one or two days, the iron of the furnace and iron mixed with cinder accumulate

round the nose of the tuyere and begin to adhere to it, or in technical language the tuyere "irons," as shown at A A in Fig. 4. As this accumulation goes on increasing, the entrance of the blast into the furnace is much impeded by the diminution of the tuyere aperture. In the case of the wrought iron tuyere, the tuyere has then to be taken out and changed, an operation attended with much labour and occupying about three quarters of an hour, during which time the blast has to be taken off the furnace; whilst in the cast iron tuyere, when it has "ironed" badly, the accumulation of iron round the cast iron nose is so great as to render it necessary to shut off the water and burn off the entire end of the tuyere, before the tuyere can be taken out; this burning off requires several hours to accomplish, during which time the good working of the furnace is interfered with, while the value of the tuyere and nozzle pipe is of course sacrificed.

The new tuyere, forming the subject of the present paper, is shown in Figs. 5 and 6, Plate 72, and is made of Gunmetal, that is copper alloyed with small proportions of tin and spelter. As copper whether pure or alloyed has no affinity whatever for iron, no iron or other material from the furnace becomes attached to the tuyere nose, however long a time it may have been in the furnace: in fact the gunmetal tuyere never "irons," and therefore rarely requires to be taken out or changed, from which circumstance many advantages arise.

After various experiments had been made by the writer as to the form and thickness of tuyeres made entirely of gunmetal in different proportions, and also with tuyeres having the outer end made of iron and only the nose end of gunmetal, the form of the ordinary wrought iron tuyere was adopted, as shown in Figs. 5 and 6. Fig. 6 represents the longitudinal section of a gunmetal tuyere, 20 inches long, 11 inches diameter at the outer end, and 8 inches at the nose end, with $3\frac{1}{2}$ inches diameter of opening: the wrought iron nozzle B of the blast pipe is also shown in its place in the axis of the tuyere. Fig. 5 is an elevation of the back end of the tuyere, showing the position of the two water holes.

In this tuyere, instead of the supply water pipe C being simply inserted into the back end, as is the case in the wrought iron tuyeres, without entering the water space, the pipe is carried forwards inside the tuyere to within 4 or 5 inches of the nose end, so that the fresh cold water is delivered close to the nose end, which has been found to ensure a more effective action of the water in keeping the tuyere nose cool.

The first gunmetal tuyere of nearly this form was put to work at the writer's furnaces at Willenhall on 18th January last, and has been at work ever since until last week, when it was taken out for the purpose of being sent to the present meeting, and is now exhibited. There is also exhibited a gunmetal tuyere of the pattern since more generally adopted, which has been at work for three months in the same furnaces; and also an ordinary wrought iron tuyere taken out after only a few days' work, showing how the nose "irons." With respect to the first gunmetal tuyere now exhibited, it has to be observed that when first cast it was an imperfect casting, and was patched by running some gunmetal over part of the nose end a second time; notwithstanding this disadvantage however it has worked for nine months with scarcely any signs of failing. Another fact deserving of special notice in connection with this first gunmetal tuyere is that it was originally cast 1 inch thick at the nose, but after being put to work it got gradually reduced to its present thickness of about $\frac{1}{2}$ inch; this took place by small holes forming in the metal at the nose end and the surface getting gradually melted down until it arrived at the proper thickness, since which time there has been no further change of any consequence. This thickness of $\frac{1}{2}$ inch at the nose is therefore the one which has now been permanently adopted, and the sides of the tuyere are made $\frac{3}{8}$ inch thick. A specimen of a gunmetal tuyere slotted down the centre is also shown.

As gunmetal melts at a lower temperature than iron, a full and constant supply of water from a head or cistern raised a good height above the tuyeres must be kept continually flowing through these gunmetal tuyeres; and for the same reason it is of importance

when the tuyere is changed that the water should be kept on till the tuyere is quite ready to come out. When the tuyere is to be taken out, a sharp bar must not be employed to loosen it, such as is used in the case of the ordinary wrought iron tuyeres; but a round-ended bar with the head projecting on one side so as to fit the end of the gunmetal tuyere, as shown in Fig. 8, Plate 73, answers the purpose completely. If these points are carefully attended to, the nose of the tuyere is found not to be liable to be injured or cut off.

The water cistern for the supply of the tuyeres should be placed at a height equal to that of the furnace, wherever practicable, in order to ensure a rapid circulation of water. The water pipes to the tuyere are 1 inch bore, and a little hemp and white lead is put round the pipes where they are inserted into the tuyere, to make a water-tight joint; and a few inches behind the joint a small collar D is welded on the pipe, Fig. 6, to serve as a butt for the furnaceman's hammer to strike against for driving up the water pipe tighter.

If a deposit of sediment is found to be formed in the gunmetal tuyere from the water that is supplied to the tuyere, it should be allowed to become quite cold when taken out, and then on its being knocked with a hammer the scale is all easily detached from the metal and falls out. If however the water is allowed to flow through the tuyere in a good stream, so that the water is always cool, but little sediment is deposited, as it is only boiling water that causes much scale. In the ordinary wrought iron tuyere on the other hand it is usual to keep the water as hot as possible, because it is found that the tuyere then "irons" less, although there is more deposit of sediment in consequence. But as the gunmetal tuyere never "irons," the colder the water is kept, the better; and in practice the water running away from the gunmetal tuyere is only slightly warmed.

On putting a new hearth and boshes into a furnace where the gunmetal tuyeres are used, the tuyere openings may be built smaller than is usual, because a large hole is not required to be made around the tuyere for getting it out, as is requisite with the

ordinary wrought iron tuyeres. This affords additional substance and strength to the furnace hearth.

Amongst the advantages of the gunmetal tuyeres are the saving of labour and the comfort to the furnacemen, especially in hot casting houses, where the labour of changing a tuyere that has "ironed" is very severe and exhausting, on account of the quantity of hard-set material that impedes its being taken out. On account of the saving of time in tuyering, the length of time that the blast is off the furnace at casting time is shortened half an hour, both night and morning, as compared with the ordinary wrought iron tuyeres; and when it is borne in mind that the operation of casting is repeated more than 600 times in a year, it is obvious that this saving must amount to a considerable gain in the make of iron during the year.

The gunmetal tuyere is readily changed in a quarter of an hour, instead of requiring three quarters of an hour as in the case of the ordinary wrought iron tuyeres; and it only requires to be changed when the tuyere sides work hot, which, if the supply of water is duly kept up, can only occur from accumulation of sediment inside the tuyere. At the writer's furnaces at Willenhall the same gunmetal tuyere has at times continued at work for three entire months without once changing; nor have any of the gunmetal tuyeres been injured or met with any accident since they were first put to work there nearly ten months ago.

In consequence of the size of aperture of the gunmetal tuyere remaining unchanged during working, instead of becoming gradually diminished by the accumulation of iron on the nose, as in the wrought iron tuyere, the blast enters the furnace freely, and the size of the nozzle pipes B has accordingly been reduced with the gunmetal tuyeres: this has also been found necessary at the Parkfield Furnaces, near Wolverhampton, and other furnaces where the gunmetal tuyeres are in use. This is advantageous as producing regularity in the supply of blast entering the furnace. There is also an important saving in fuel and wages with the gunmetal tuyeres.

The above advantages are found to be obtained from the gunmetal tuyeres, when they are carefully used; at the same time, like all improvements, they require some little care and attention at first to ensure their success, especially on the part of furnace managers. It is necessary to see that the water is kept on by night as constantly as by day; and that the tuyeres receive fair play in every respect from the workmen. An alarm whistle may be attached to the supply water pipe of the tuyere, to be acted on by the blast and give immediate warning in case of the water supply ever failing. There is generally a prejudice in the minds of furnacemen against any novelty, and the blacksmiths especially connected with blast furnaces may naturally be expected not to be favourably disposed towards what they regard as depriving them of a great part of their employment. When this prejudice however is once overcome, the furnacemen themselves have been found to be foremost in recognising the advantages and saving of the gunmetal tuyeres.

In Fig. 7, Plate 73, is shown a longitudinal section of an improved gunmetal tuyere having the inside made parallel or cylindrical for a distance of 4 inches from the nose end, so that the tuyere itself forms the blast nozzle of $2\frac{3}{4}$ inches diameter, while the end of the blast pipe B of 4 inches diameter is inserted into the taper part of the tuyere as far as it will go, and rammed up tightly with fireclay stopping. This form of tuyere is considered by the writer to be a great improvement on the form originally adopted for the gunmetal tuyeres, because the effect of the cylindrical nozzle is that the blast is projected with more force straight into the furnace, and to a greater distance than from a nozzle pipe which tapers to the end; for a tapering nozzle favours the divergence of the blast, and too much taper is especially injurious, by causing the destruction of the brickwork round the tuyere inside the furnace. The inside of the parallel nozzle is cast large enough to be bored out so as to ensure its being perfectly cylindrical. In case of requiring to blow with a larger nozzle, say 4 inches diameter instead of $2\frac{3}{4}$ inches, the tuyere itself must be made exactly to that extent of $1\frac{1}{4}$ inch larger in diameter at both ends; or if a smaller nozzle is wanted, of only 2 or $2\frac{1}{4}$ inches diameter, the tuyere must be diminished in the same

way at both ends: this will ensure the proper taper of the back end of the tuyere, and the right position of the blast pipe, and no other alteration will be required in the shape or size of the tuyere.

Mr. SOLLY exhibited specimens of the gunmetal tuyeres, one of which had been nine months at work, and still did not show any signs of injury; and he explained that they had only been removed from the blast furnace for the purpose of being exhibited to the meeting. He showed also one of the ordinary wrought iron tuyeres, which had had to be taken out after only three days' work, in consequence of having ironed very badly at the nose. At his own works he had never had a single gunmetal tuyere injured since they were first put to work about ten months ago; and he believed that had also been the experience at all other furnaces where the gunmetal tuyeres were in use, provided they were worked entirely with "mine." But at one furnace worked with cinder, a scaffolding had taken place in the furnace, so that the charge had stuck fast and accumulated at a certain height above the tuyeres; and when a sudden drop of the material took place, it had cut into the tuyeres, and it had been necessary to have the tuyeres taken out and recast. The accident was owing to the boshes of the furnace not being in good order and not being sufficiently inclined.

The CHAIRMAN enquired what was the cost of the gunmetal tuyeres, as compared with the ordinary wrought iron tuyeres.

Mr. SOLLY replied that the gunmetal tuyeres cost between £5 and £7 each, according to the size of the tuyeres and the quality and cost of the gunmetal employed, the expense of casting the tuyeres being but little more than in the case of ordinary brass castings. An ordinary wrought iron tuyere weighed about 140 lbs., and the cost of the iron was about 10*s.* per cwt., while the labour expended upon the manufacture amounted to 2½*d.* per lb., so that the entire cost was about £2, or about one-third the cost of the gunmetal tuyeres.

The wrought iron tuyere however was speedily destroyed by the ironing in the blast furnace; while the gunmetal tuyeres were not only very durable, but whenever they had to be replaced, could be recast with scarcely any loss of metal. It must further be borne in mind that the cost of the tuyeres themselves was of very little consequence in comparison with the waste of material in the furnace and the consequent loss of make of iron from the furnace having to be kept standing with the blast off, whenever the ordinary wrought iron tuyeres required attention; and in this respect the use of the gunmetal tuyeres effected a saving which far outweighed their extra cost.

The CHAIRMAN enquired what was the average length of time that an ordinary wrought iron tuyere was found to last.

Mr. SOLLY replied that it was impossible to name any particular time for the duration of a wrought iron tuyere, as it was altogether a matter of chance how long it would work. The wrought iron tuyere now exhibited had worked only three days after being first put in new; and the longest time that he had known one last was not more than three or four months, during which the tuyere had required frequently taking out for repairs, and it had become at length so much shortened by continually cutting off the extremity of the nose that it could no longer be made use of. The specimens that were exhibited of the gunmetal tuyeres on the other hand, one of which had been in constant work for nine months, showed at present no signs whatever of even becoming worn.

Mr. ADDENBROOKE said he had made a trial of one of the gunmetal tuyeres, and found that it lasted without giving the slightest trouble during the time that a large number of wrought iron tuyeres blowing the same furnace had to be successively replaced; and he had been so completely satisfied with the results of the trial that he had adopted the gunmetal tuyeres for both the furnaces at his works, and had entirely abandoned the wrought iron tuyeres. With regard to the extra cost of the gunmetal tuyeres in the first instance, he was convinced that it was far more than compensated for by the important practical advantages attending their use.

The CHAIRMAN enquired how many of the gunmetal tuyeres were already at work.

Mr. SOLLY replied that he had had the gunmetal tuyeres in regular work at his own furnaces for nine months past, but they had only been introduced elsewhere for about six months; and there were now about a dozen furnaces at other works blown entirely by the gunmetal tuyeres.

The CHAIRMAN moved a vote of thanks to Mr. Solly for his paper, which was passed.

The Meeting then terminated.

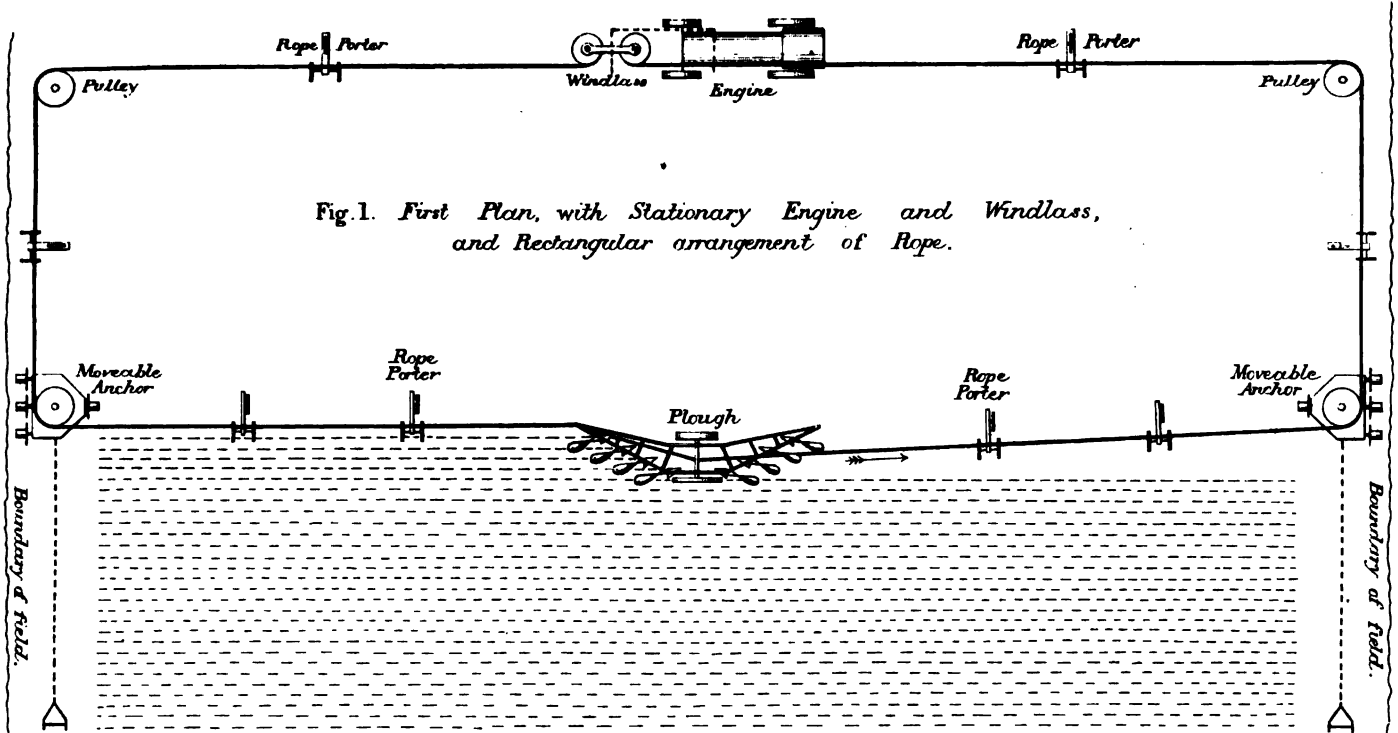
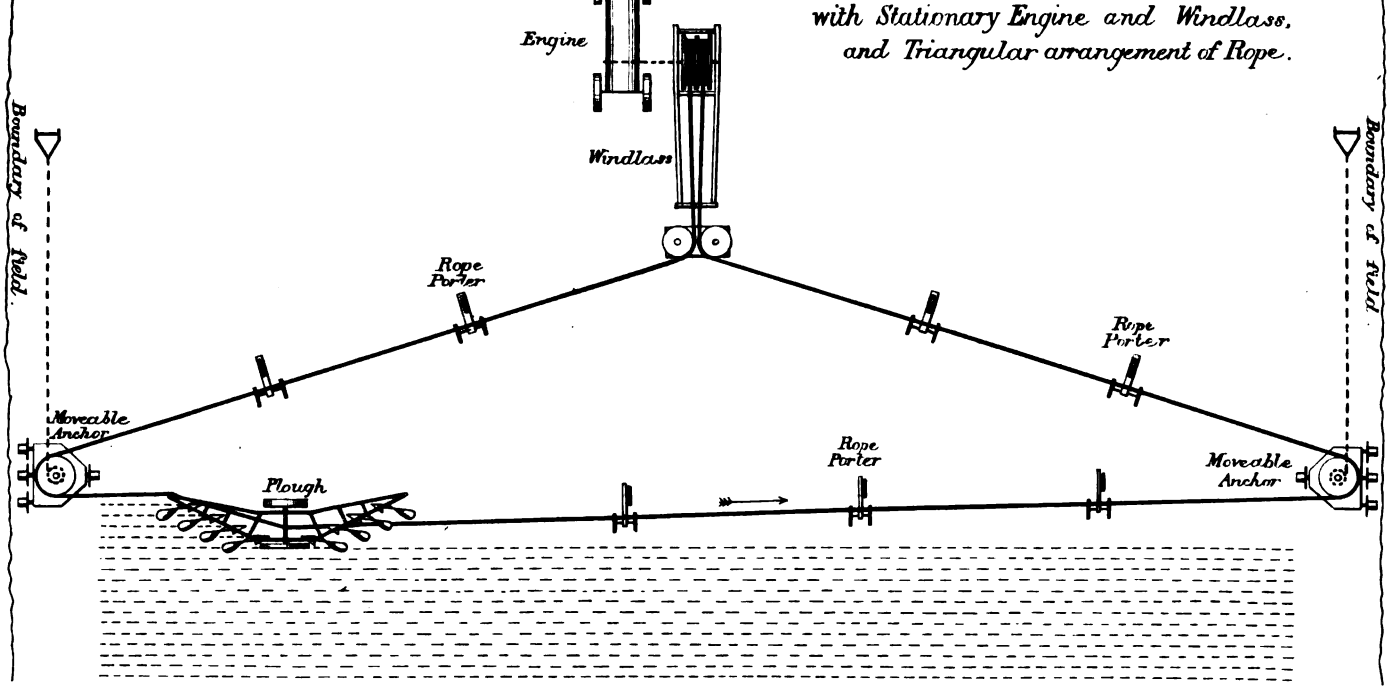


Fig. 1. *First Plan, with Stationary Engine and Windlass, and Rectangular arrangement of Rope.*

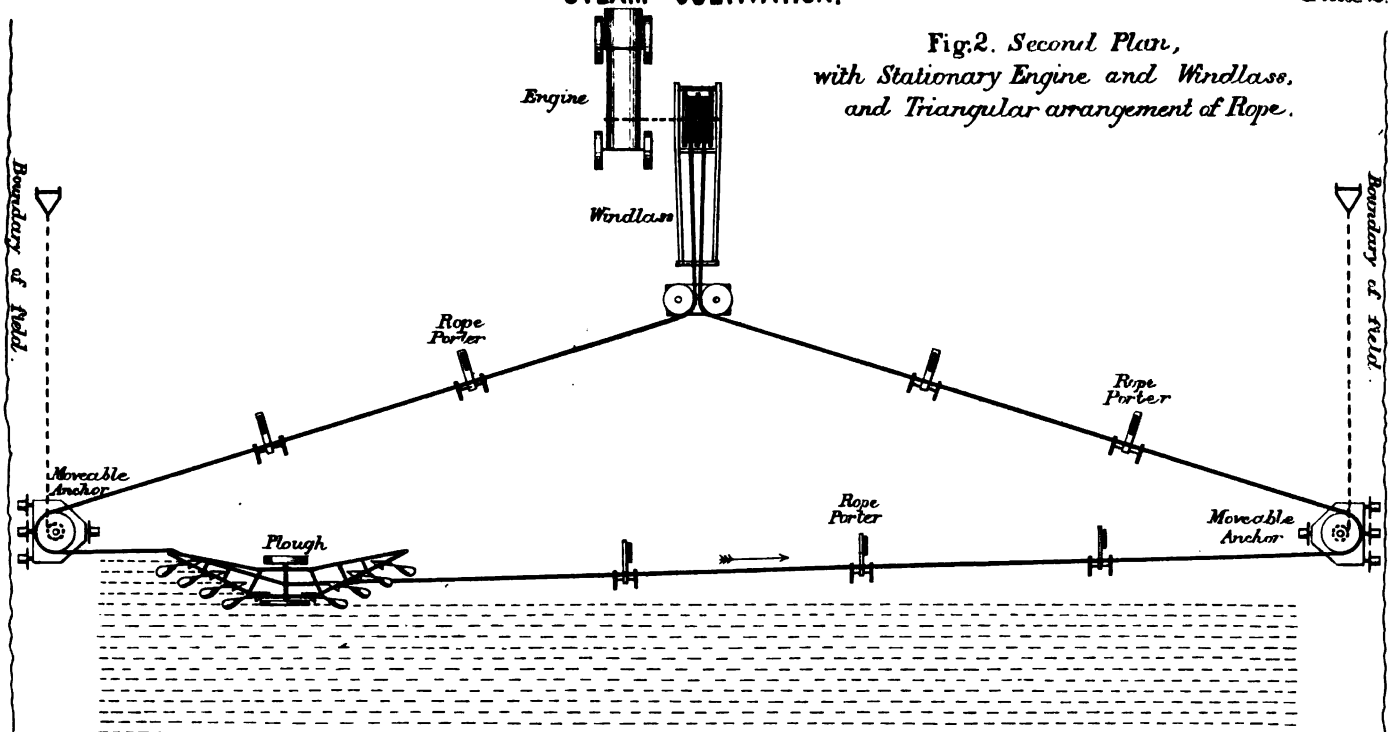
(Proceedings Inst. M.E. 1865. Page 55)



(Proceedings Inst. M. E. 1865. Page 55)

STEAM CULTIVATION.

Fig. 2. *Second Plan, with Stationary Engine and Windlass, and Triangular arrangement of Rope.*



(*Proceedings Inst. M. E. 1865. Page 55*)

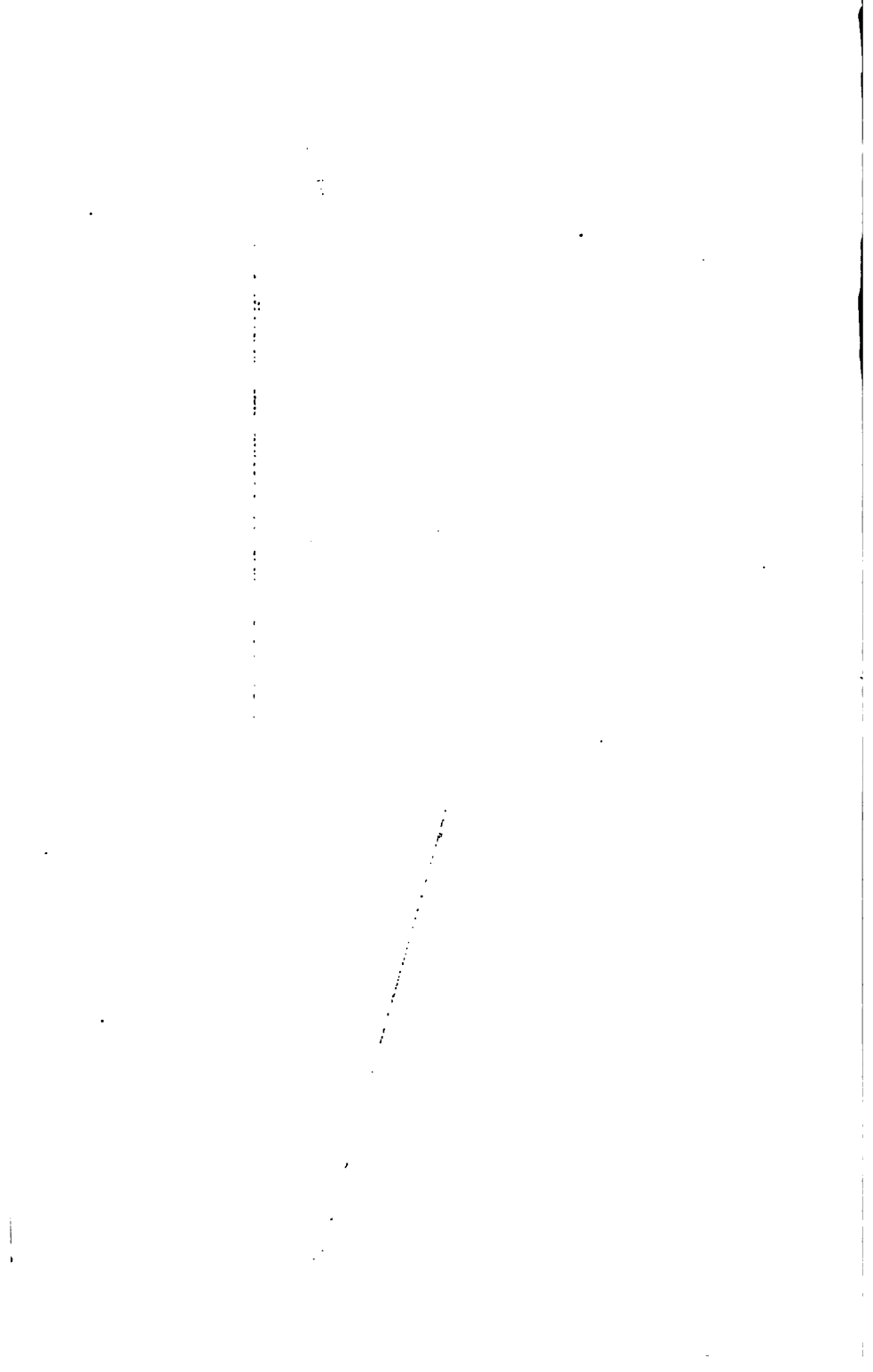
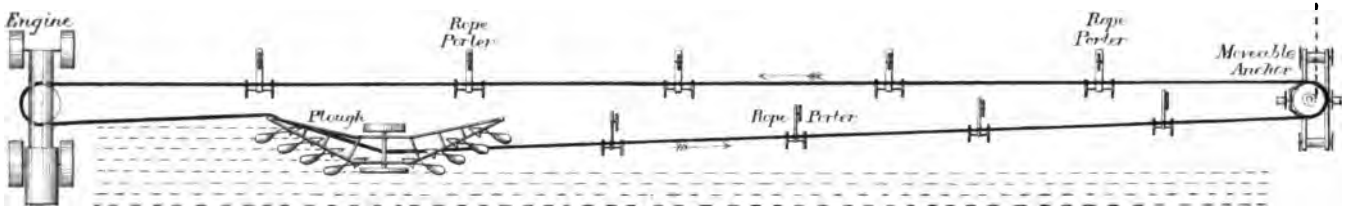


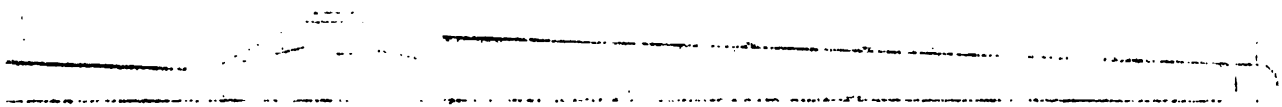
Fig. 3. *Third Plan, with Travelling Engine and Moveable Anchor, and Direct Pull upon implement.*



Boundary of field.

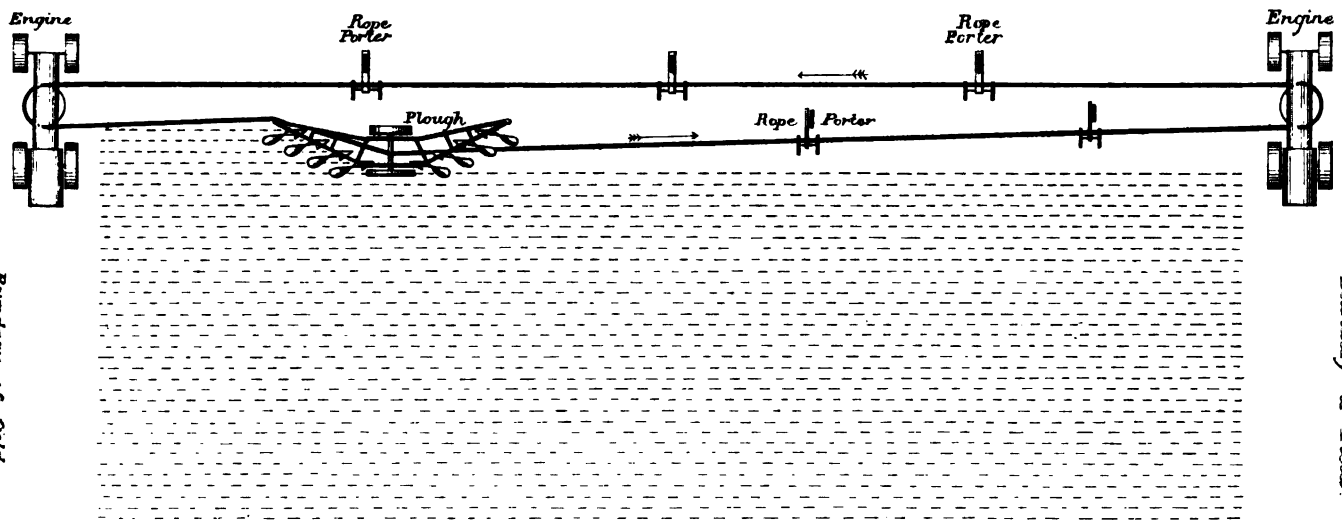
Boundary of field.

(Proceedings Inst. M. E. 1865. Page 55)



STEAM CULTIVATION.

Fig. 4. *Fourth Plan, with two Travelling Engines working in conjunction, and Direct Pull upon implement.*



(Proceedings Inst. M. E. 1865. Page 55)

LARGE ROPE PORTER.

Fig. 5. *Side Elevation.*

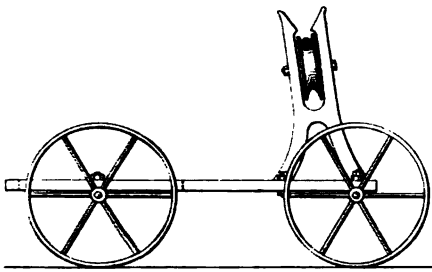


Fig. 6. *End Elevation.*

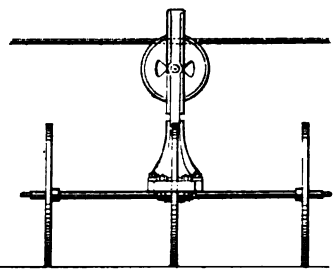


Fig. 8. *Plan of Small Rope Porter.*

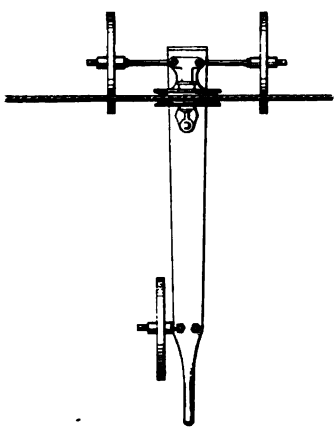
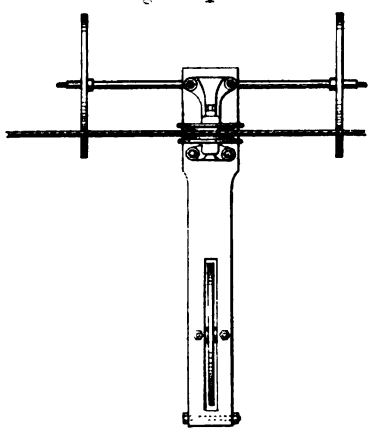


Fig. 7. *Plan of Large Rope Porter.*



SMALL ROPE PORTER.

Fig. 9. *End Elevation.*

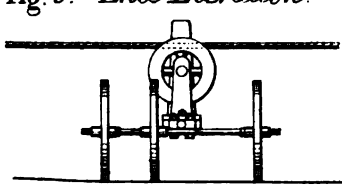
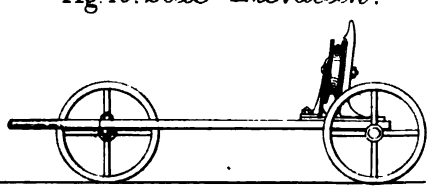


Fig. 10. *Side Elevation.*



Scale 1/30th.

Inches 0 0 1 2 3 4 5 6 7 8 *Feet.*

(*Proceedings Inst. ME. 1865. Page 55*)

STEAM CULTIVATION.

MOVEABLE ANCHOR.

Fig. 11. *End Elevation.*

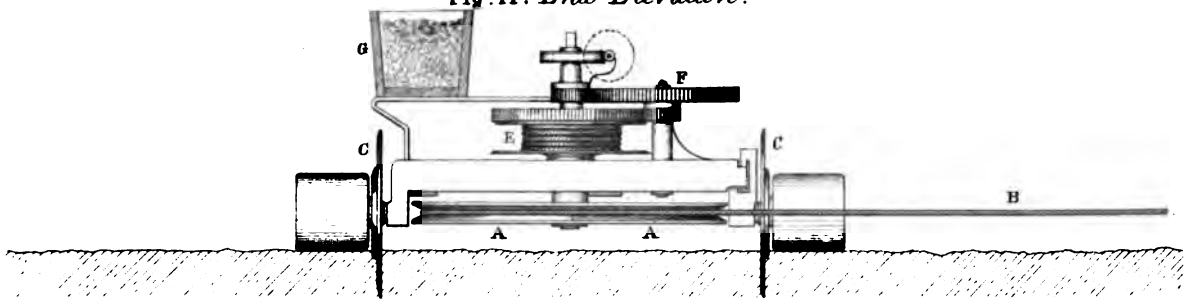
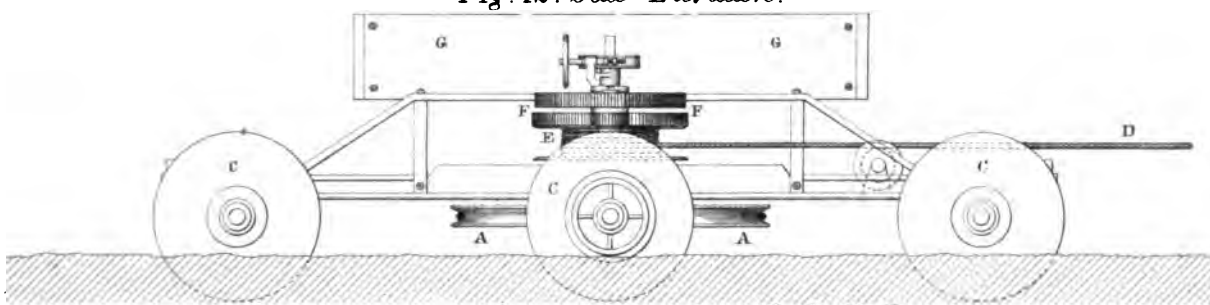


Fig. 12. *Side Elevation.*



Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1865. Page 55.)

DRIVING DRUMS.

Fig. 13. *Four-grooved Driving Drums.*

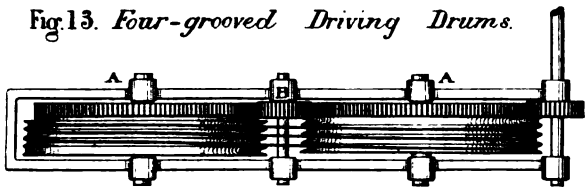


Fig. 14. *Plan.*

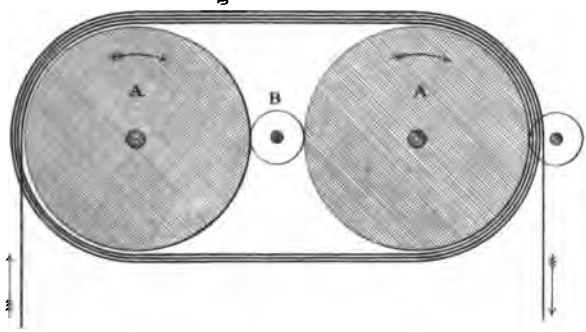
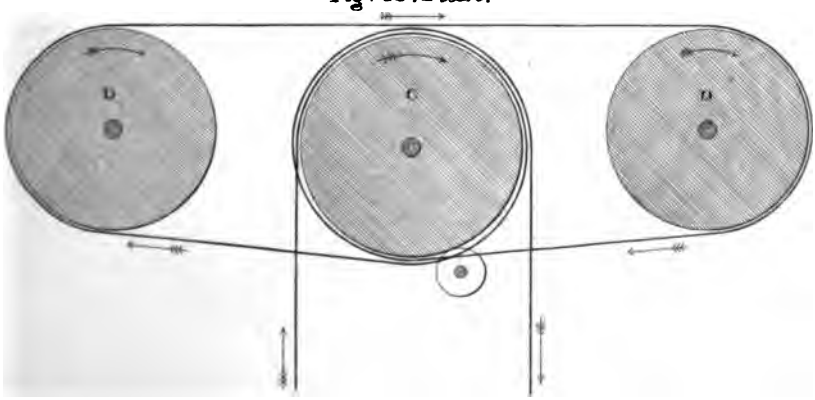


Fig. 15. V-*grooved Driving Drum.*

Fig. 16. *Plan.*



Scale 1/40th

Ins. ft. 5 0 1 2 3 4 5 6 7 8 9 10 Feet.

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CLIP DRUM.

Fig. 17. *Vertical Section.*

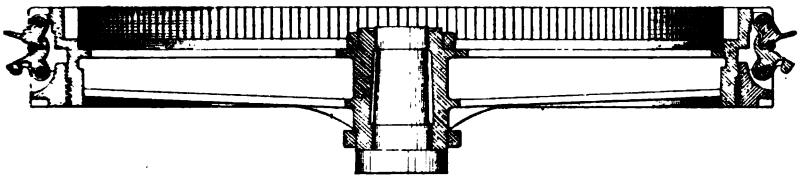
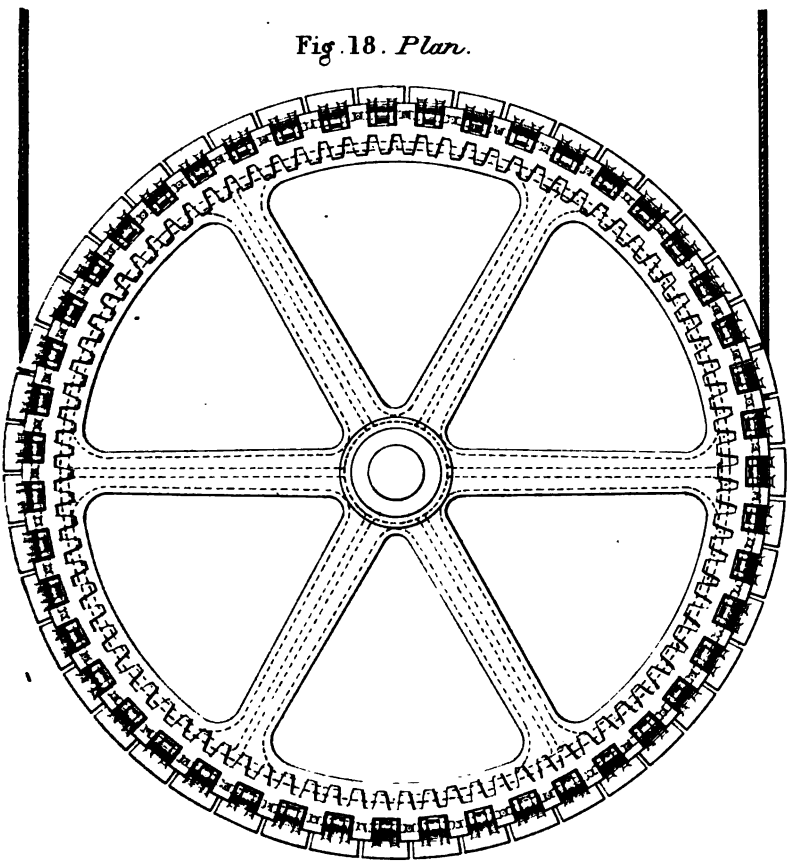
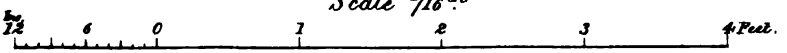


Fig. 18. *Plan.*



Scale 1/16th



(Proceedings Inst. M.E. 1865. Page 55.)

DETAIL OF CLIP DRUM, ENLARGED.

Fig. 19. *Plan of Upper Clip.*

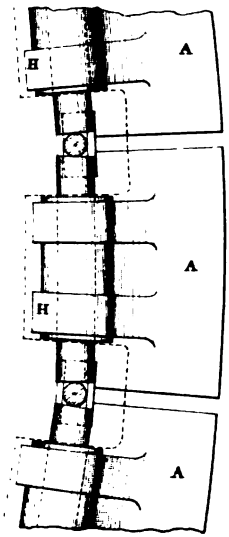


Fig. 20. *Vertical Section, showing clips Closed.*

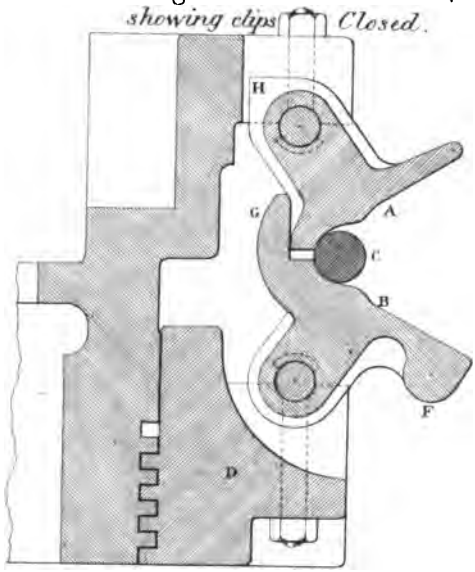


Fig. 21. *Vertical Section, showing clips Open.*

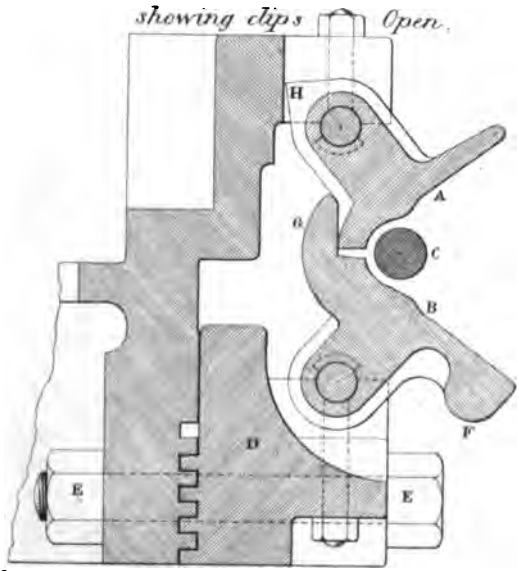


Fig. 22.

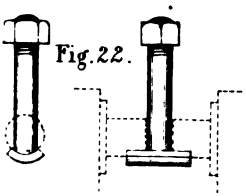
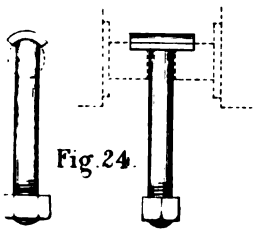


Fig. 23.

Fig. 24.



Scale 1/3rd.

0 1 2 3 4 5 6 7 8 9 10 Inches.

(*Proceedings Inst. M.E. 1865. Page 55.*)

COMPENSATING BREAK.

Fig. 25. *Plan.*

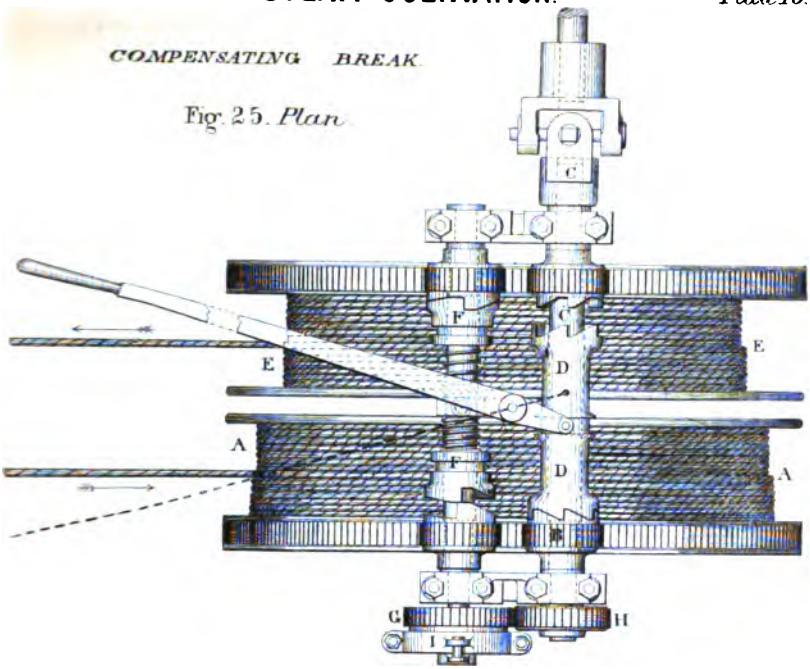
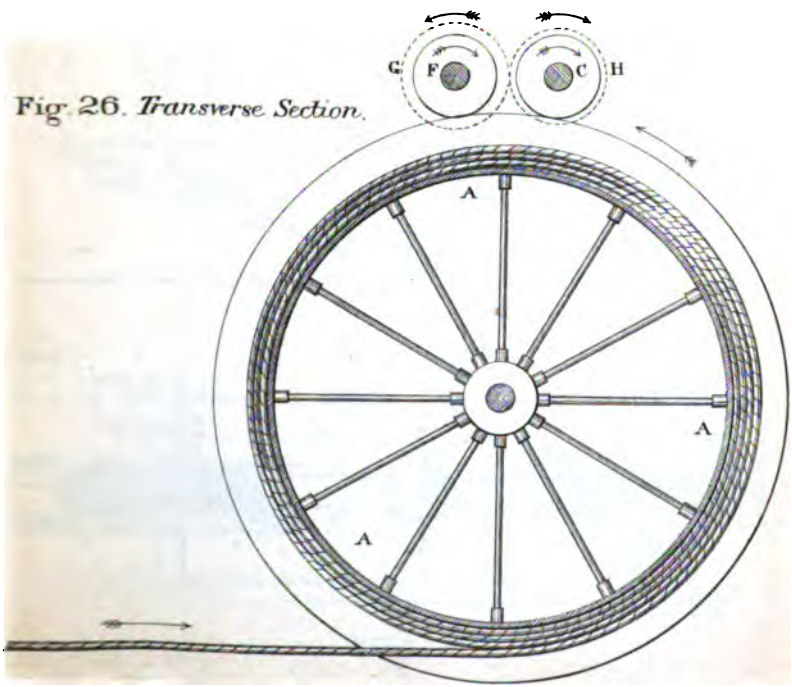


Fig. 26. *Transverse Section.*



(*Proceedings Inst. M. E. 1865. Page 55.*)

Scale 1/20th

20 0 10 20 30 40 50 Inches.

SLACK GEAR.

Fig 27. *Side Elevation of Three Furrow Plough with Slack Gear.*

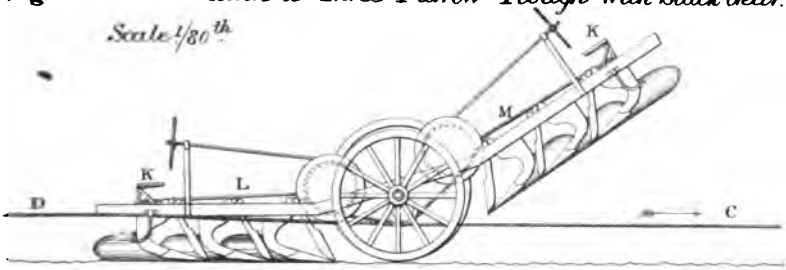


Fig. 28. *Plan.*

Fig. 29. *Side Elevation of Slack Gear, enlarged.*

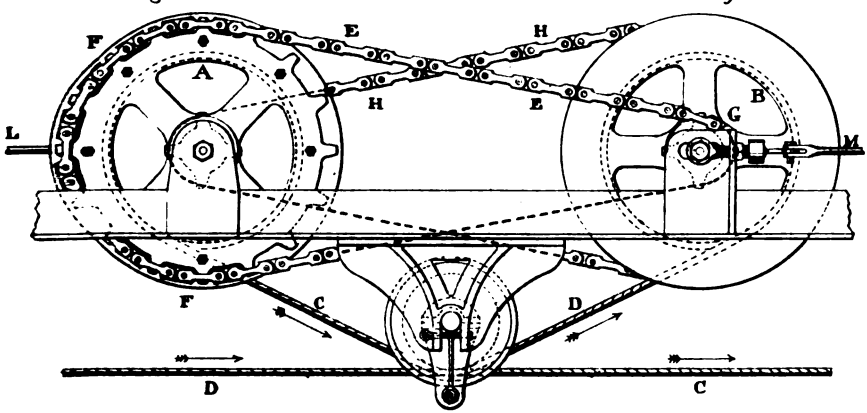
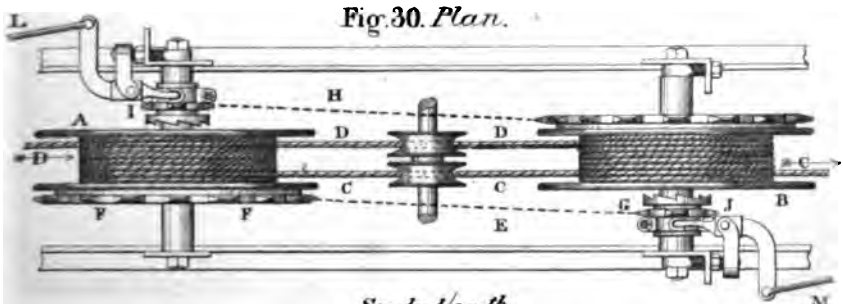


Fig. 30. *Plan.*



Scale 1/20th

10 5 0 10 20 30 40 50 Inches.

(Proceedings Inst. M.E. 1865. Page 55)

STEAM CULTIVATION.

BROAD-RIM DRIVING WHEELS.

Fig. 31. *End Elevation, partly Section.*

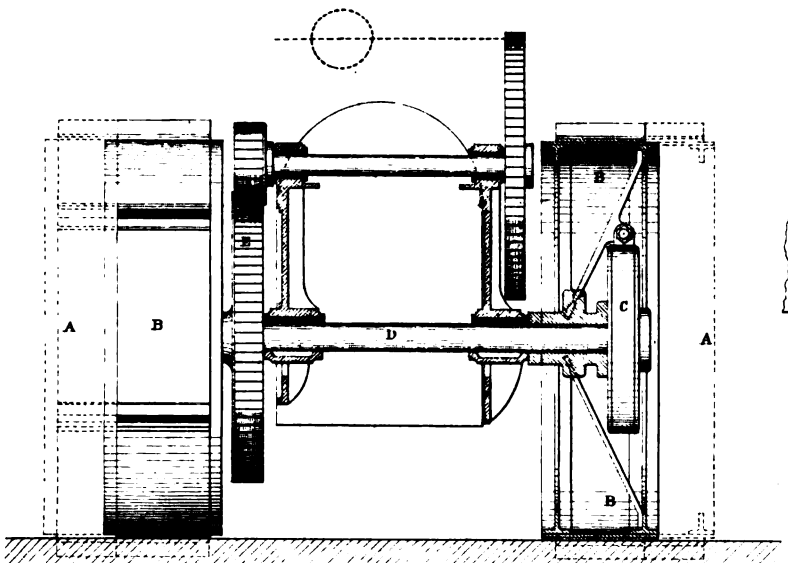
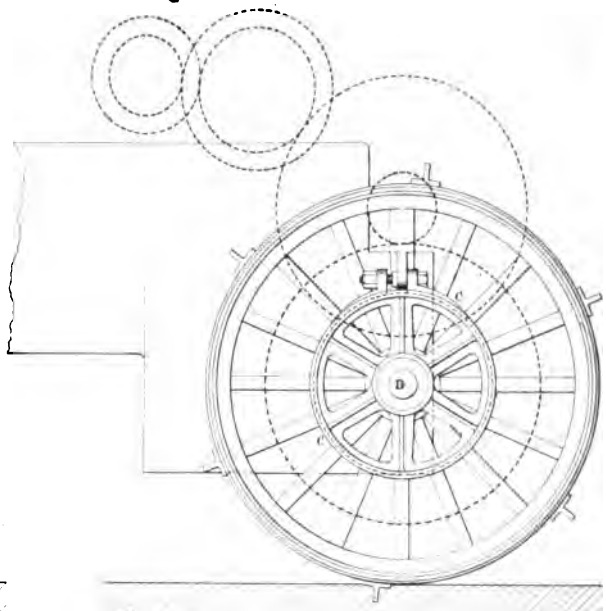


Fig. 32. *Side Elevation.*



Scale 1/30th

Inch 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

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COILING GEAR.

Fig. 33. *Vertical Section.*

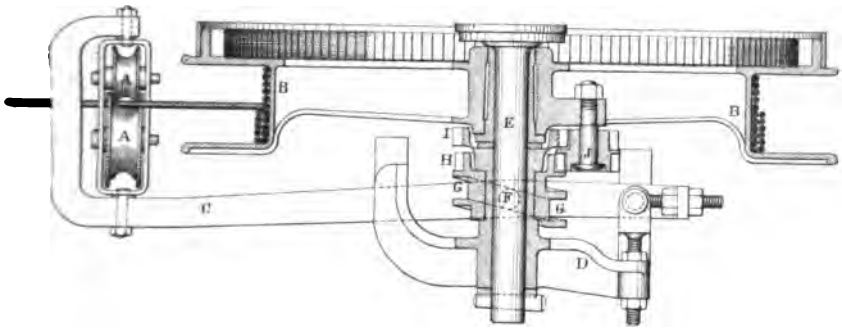
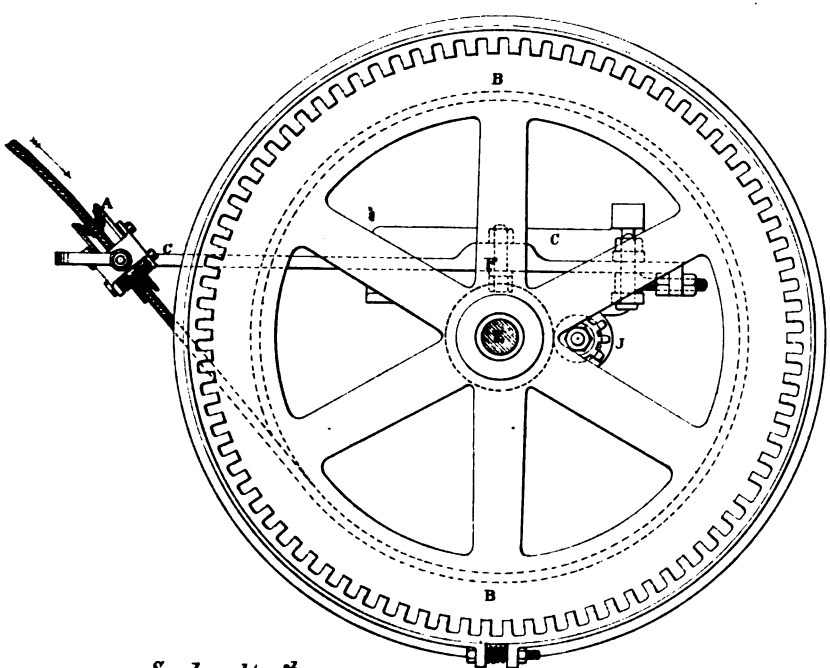


Fig. 34. *Plan.*

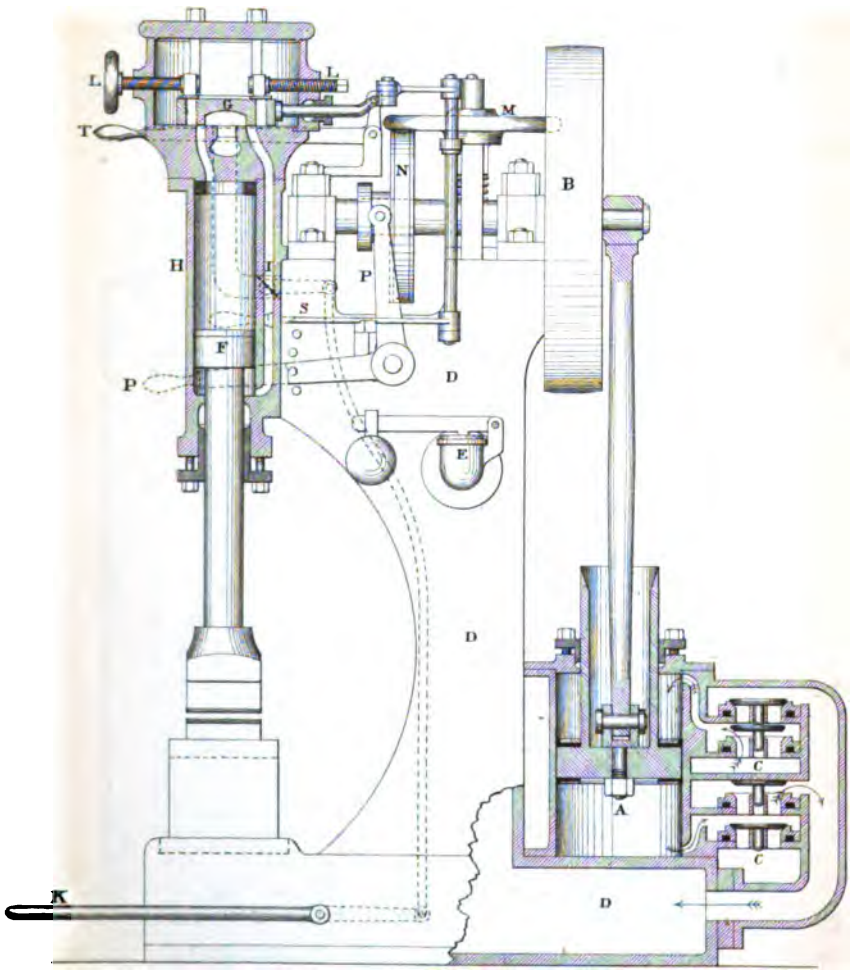


Scale 1/20th

10 5 0 10 20 30 40 50 Inches.

(*Proceedings Inst. M.E. 1865. Page 55.*)

Fig. 1. *Side Elevation, partly in Section.*



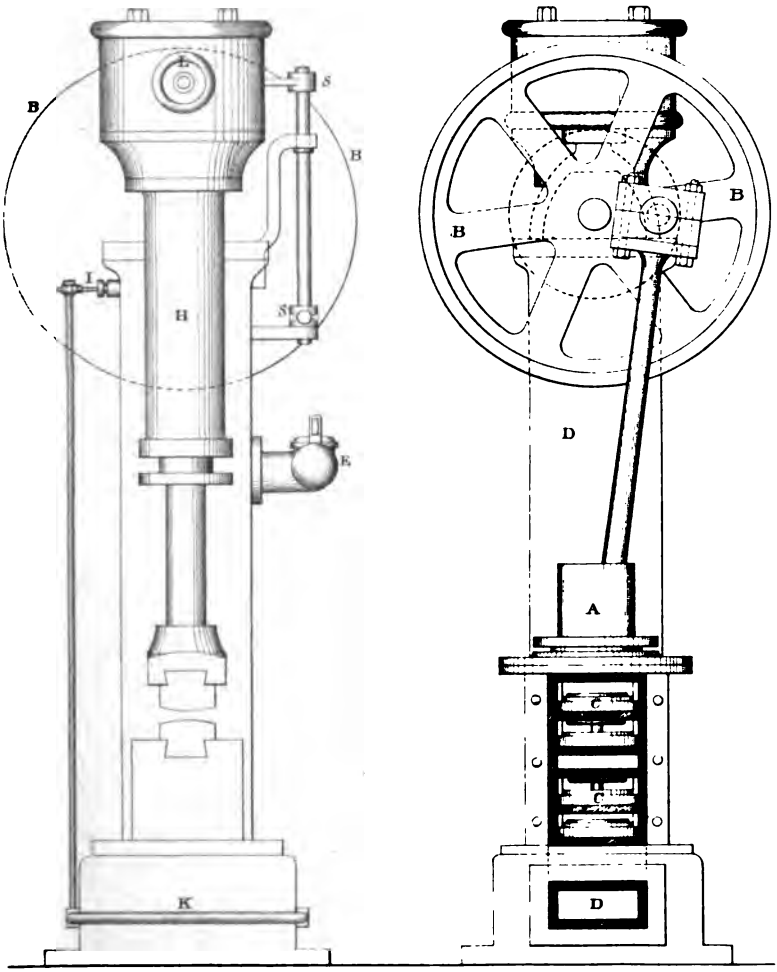
Scale 1/12th

10 5 0 10 20 30 Inches.

(Proceedings Inst. M.E. 1865. Page 94)

COMPRESSED AIR HAMMER. *Plate 15.*

Fig. 2. *Front Elevation.* Fig. 3. *Back Elevation.*



Scale 1/12th

10 5 0 10 20 30 Inches.

(Proceedings Inst. M.E. 1865. Page 94.)

Fig. 4. *Plan, partly in Section.*

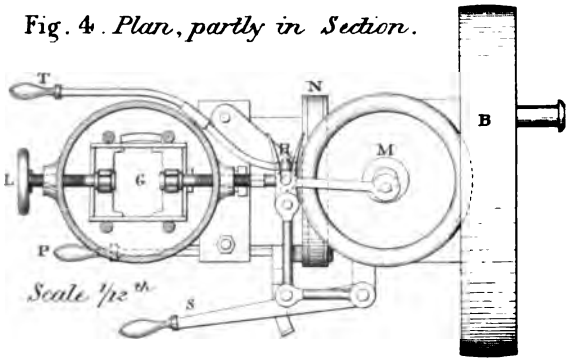


Fig. 5. *Sectional Plan thro Hammer Cylinder.*

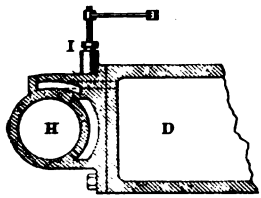
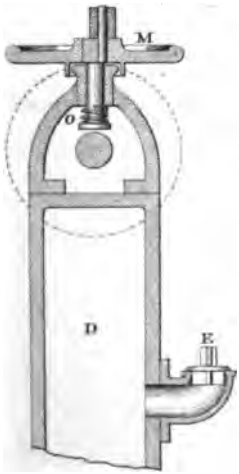


Fig. 6. *Vertical Section thro Air Reservoir.*



Scale 1/12th

0 10 20 Inches.

(*Proceedings Inst. M.E. 1865. Page 94*)

Positions of Slide Valve, enlarged. Scale 1/6th

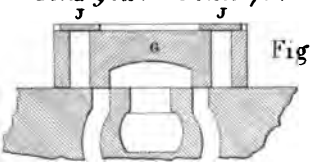


Fig. 7.

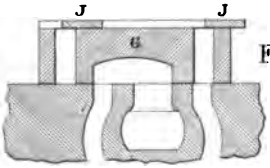


Fig. 8.

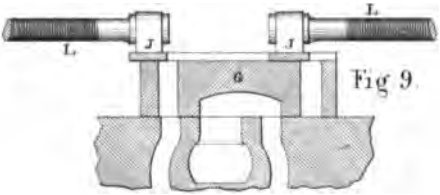


Fig 9.

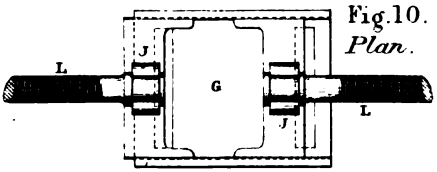
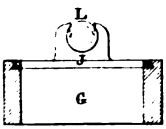


Fig. 10. *Plan.*



Transverse Section.

Fig 11.

BREAKING ROLLERS AND SCUTCHING MACHINE.

Fig. 1. *Breaking Rollers.*

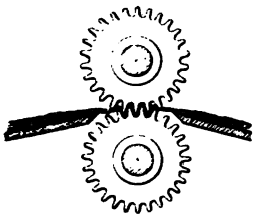


Fig. 2. *Scutching Cylinder.*

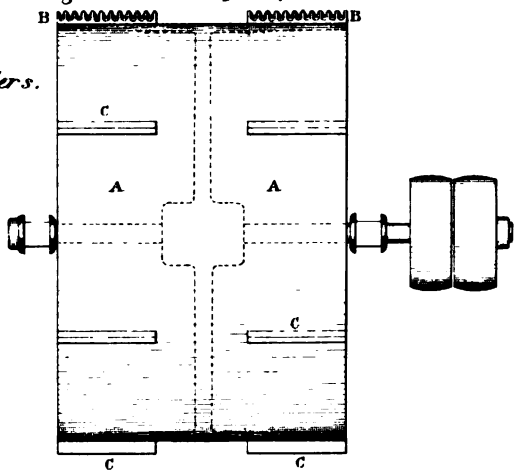
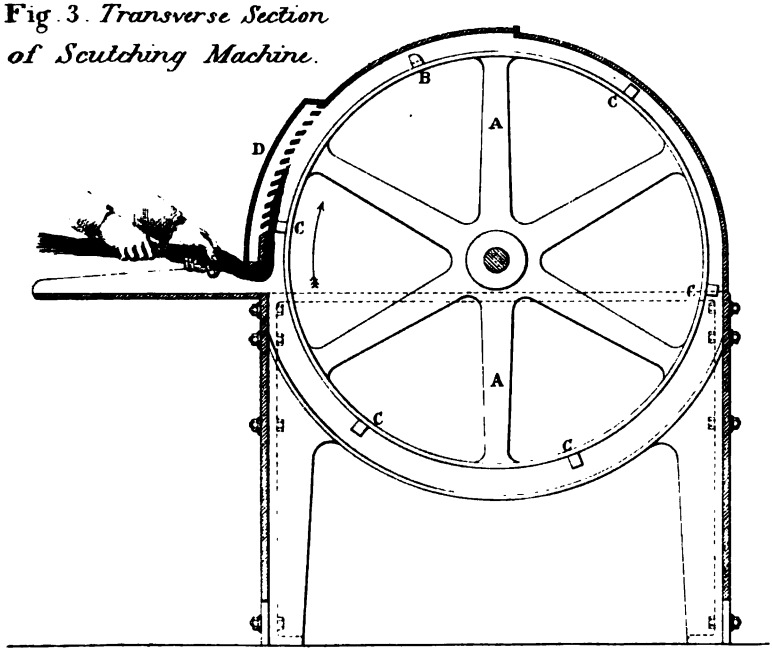


Fig. 3. *Transverse Section of Scutching Machine.*

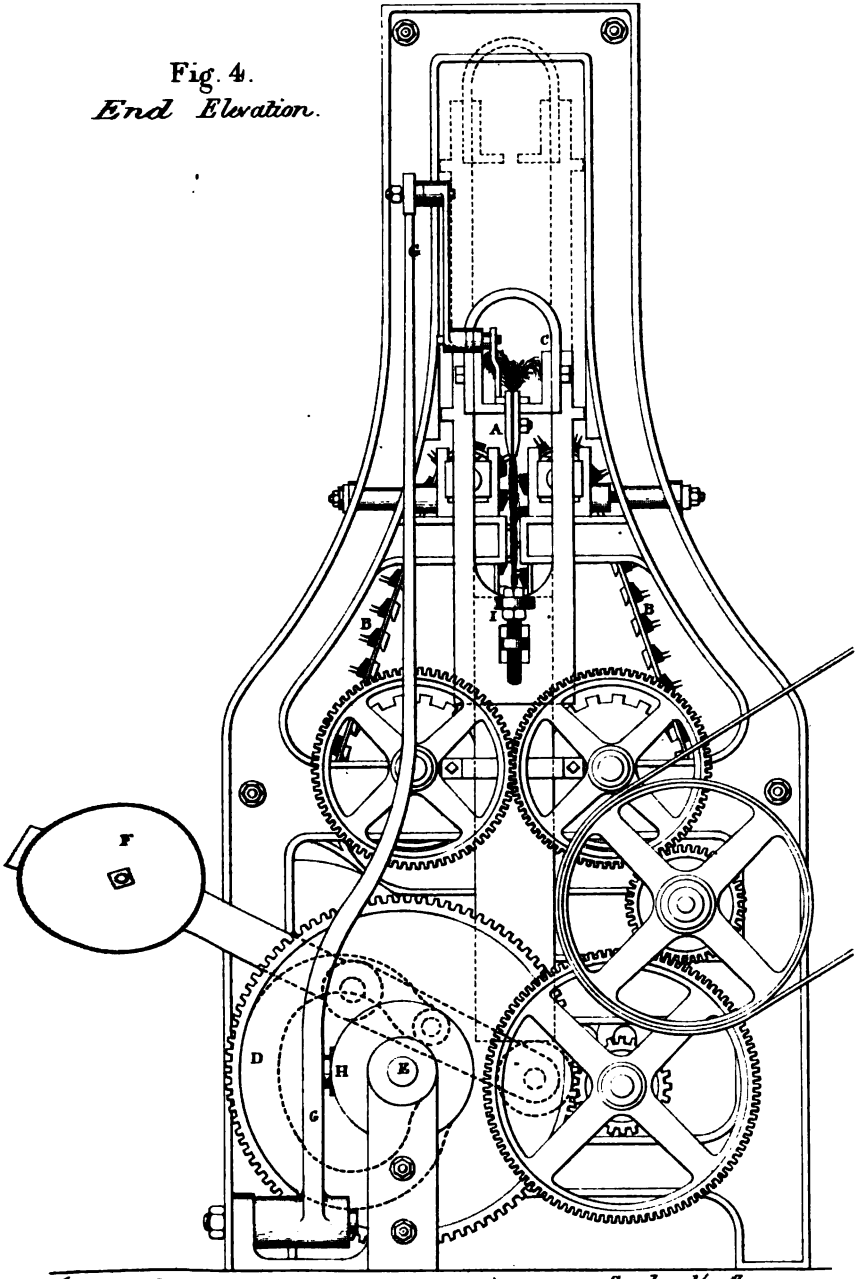


(Proceedings Inst. M.E. 1865. Page 103.) *Scale 1/16 th*

10 5 0 10 20 30 40 50 Inches.

HECKLING MACHINE.

Fig. 4.
End Elevation.

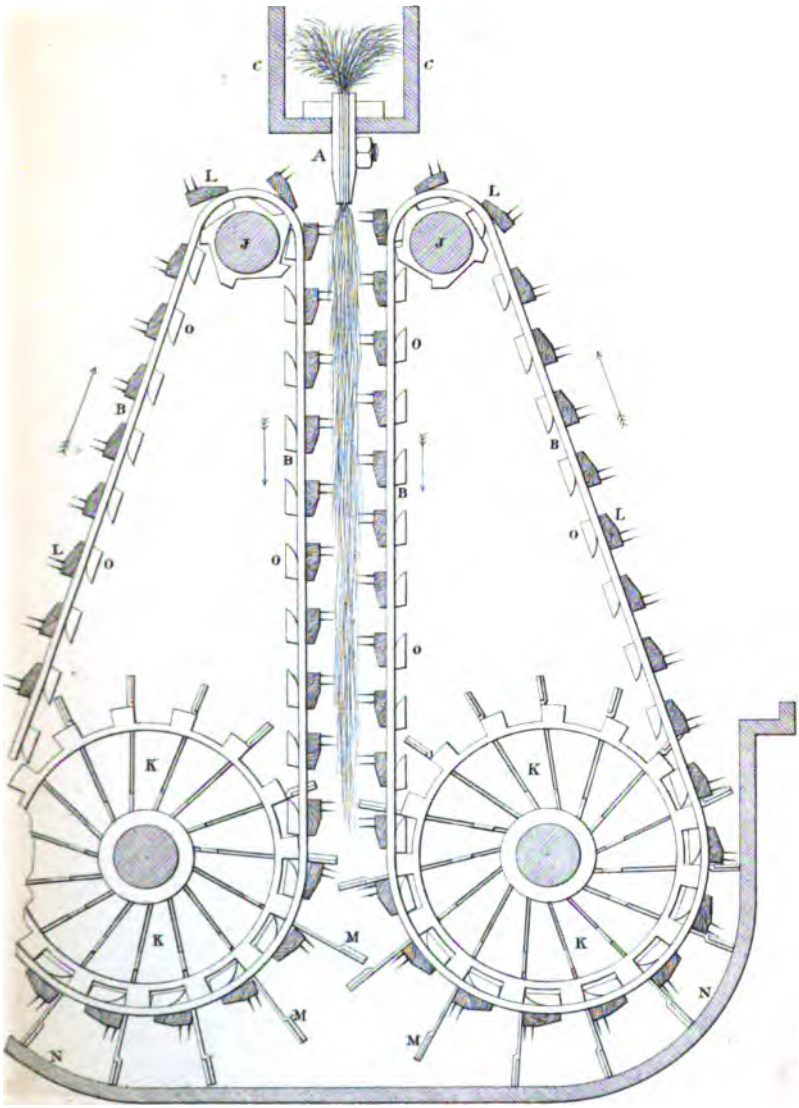


(Proceedings Inst. M.E. 1865. Page 103) *Scale 1/12th*

10 5 0 10 20 30 Inches

HECKLING MACHINE.

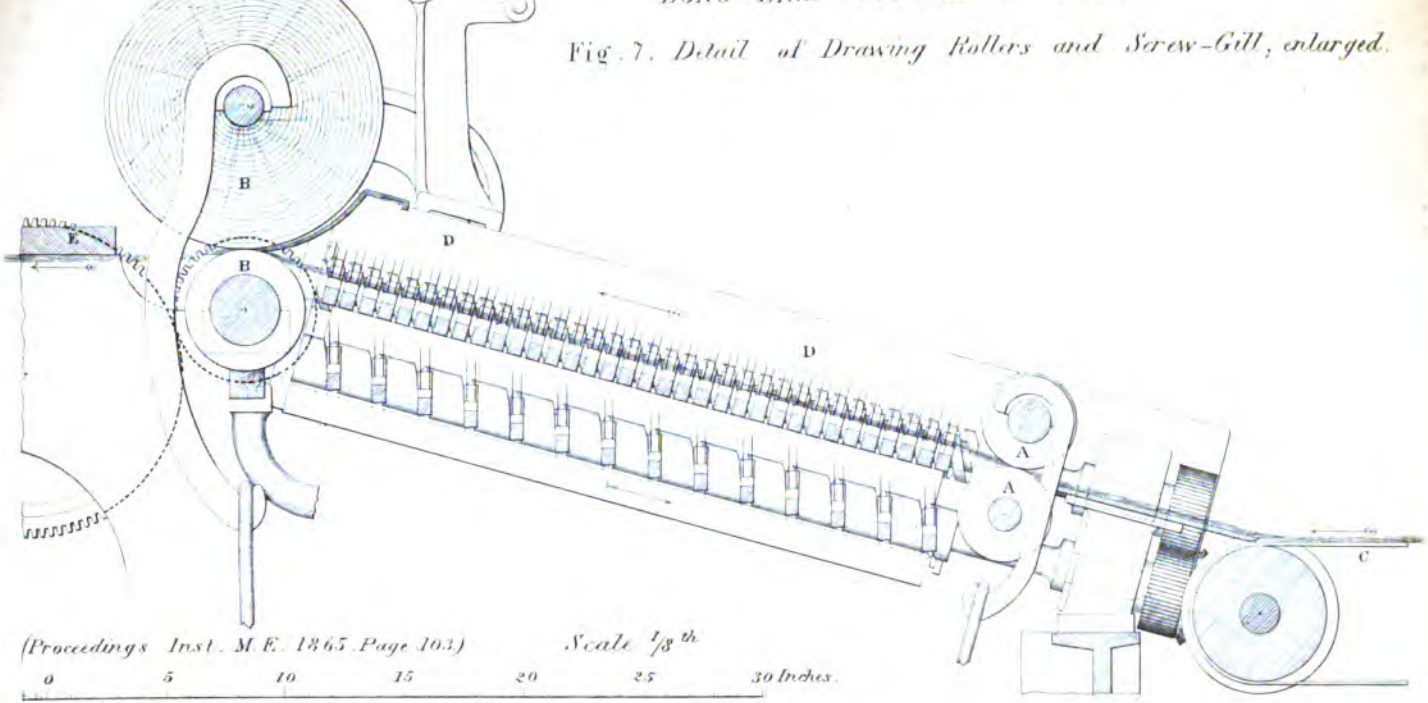
Fig. 5. *Transverse Section through Heckles, enlarged.*



(Proceedings Inst. M.E. 1865. Page 103.) *Scale 1/6th*

0 5 10 15 20 Inches

Fig. 7. *Detail of Drawing Rollers and Screw-Gill, enlarged.*



(Proceedings Inst. M.E. 1865. Page 103.) *Scale 1/8th*

0 5 10 15 20 25 30 Inches.

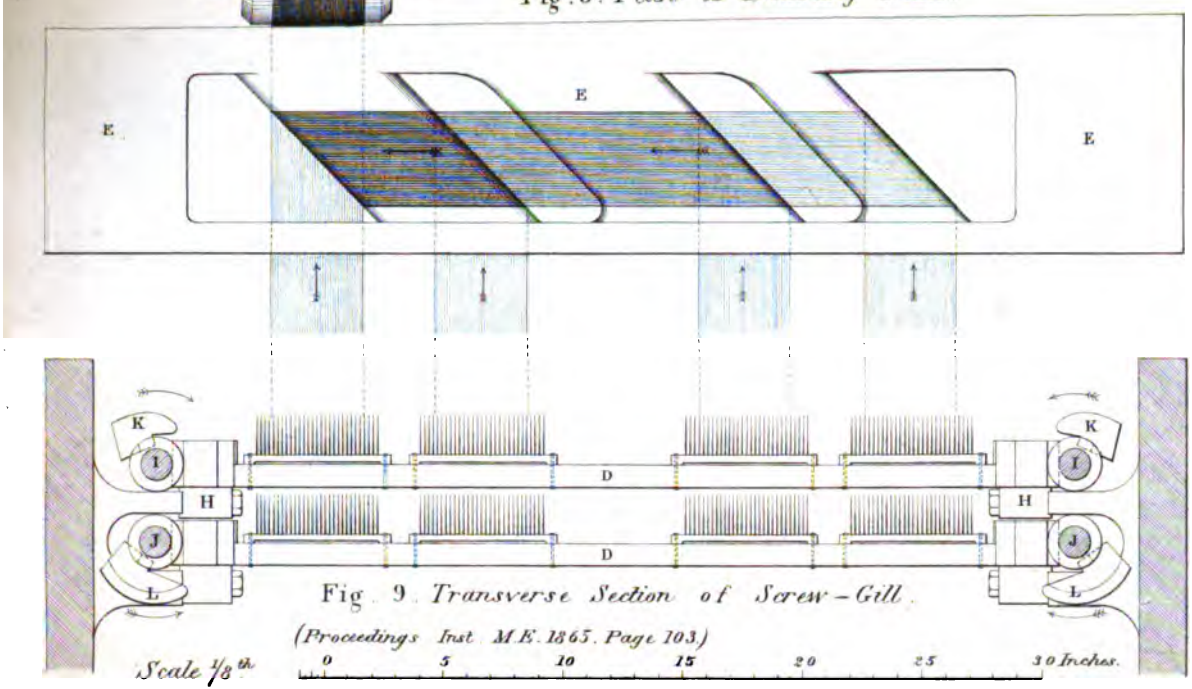


Fig. 9. *Transverse Section of Screw-Gill.*

(*Proceedings Inst. M.E. 1865. Page 103.*)

Scale 1/8th

0 5 10 15 20 25 30 Inches.

Fig. 10.

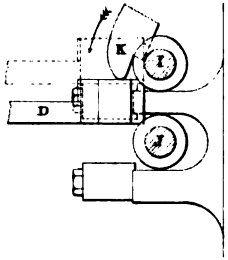


Fig. 11.

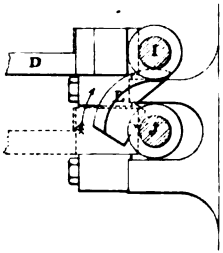
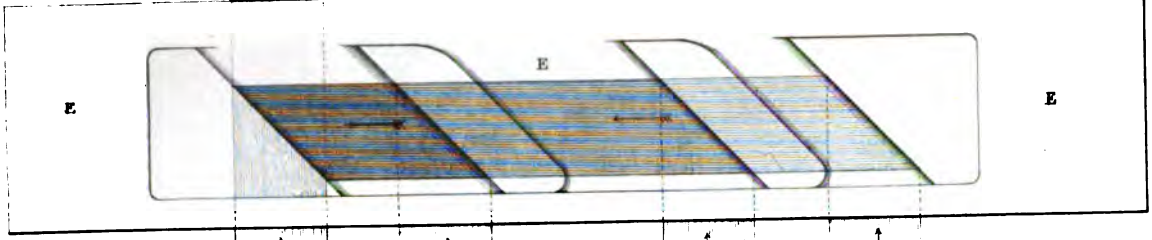
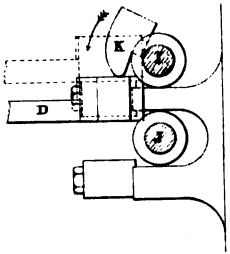


Fig. 8. Plan of Drawing Frame.

Fig. 10.





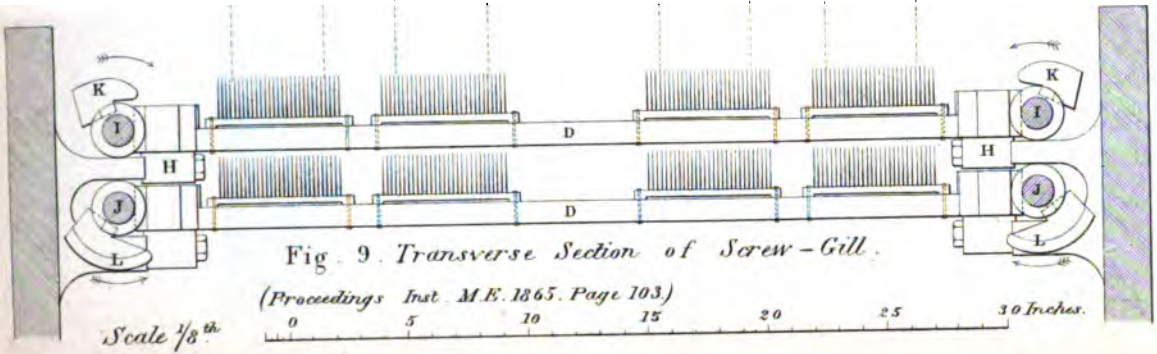


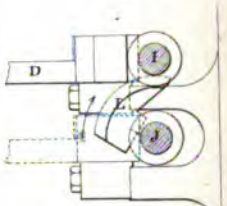
Fig. 9. *Transverse Section of Screw-Gill.*

(Proceedings Inst. M.E. 1865. Page 103)

Scale 1/8th.

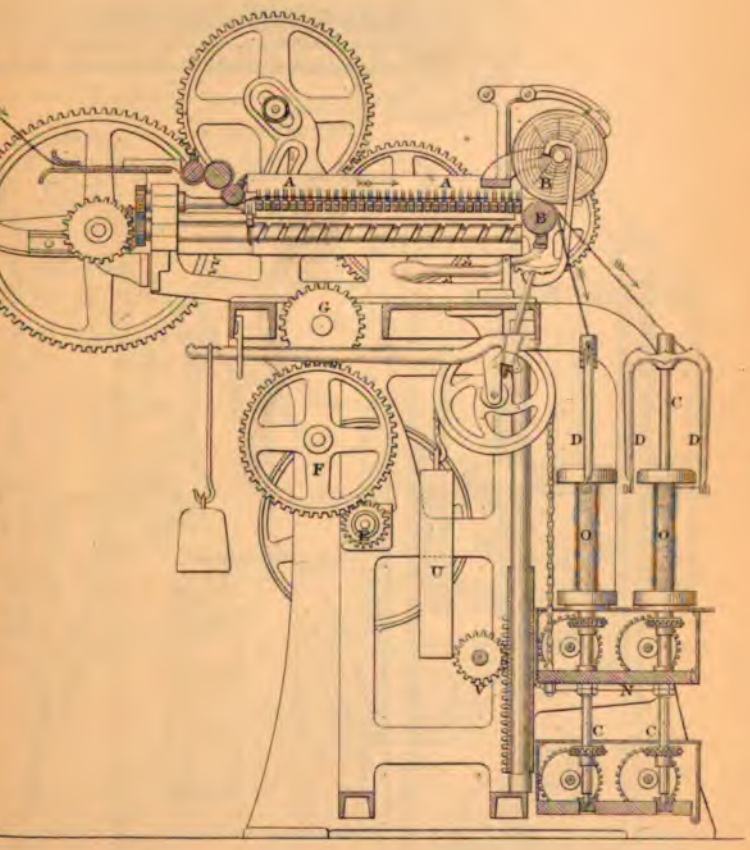
0 5 10 15 20 25 30 Inches.

Fig. 11.



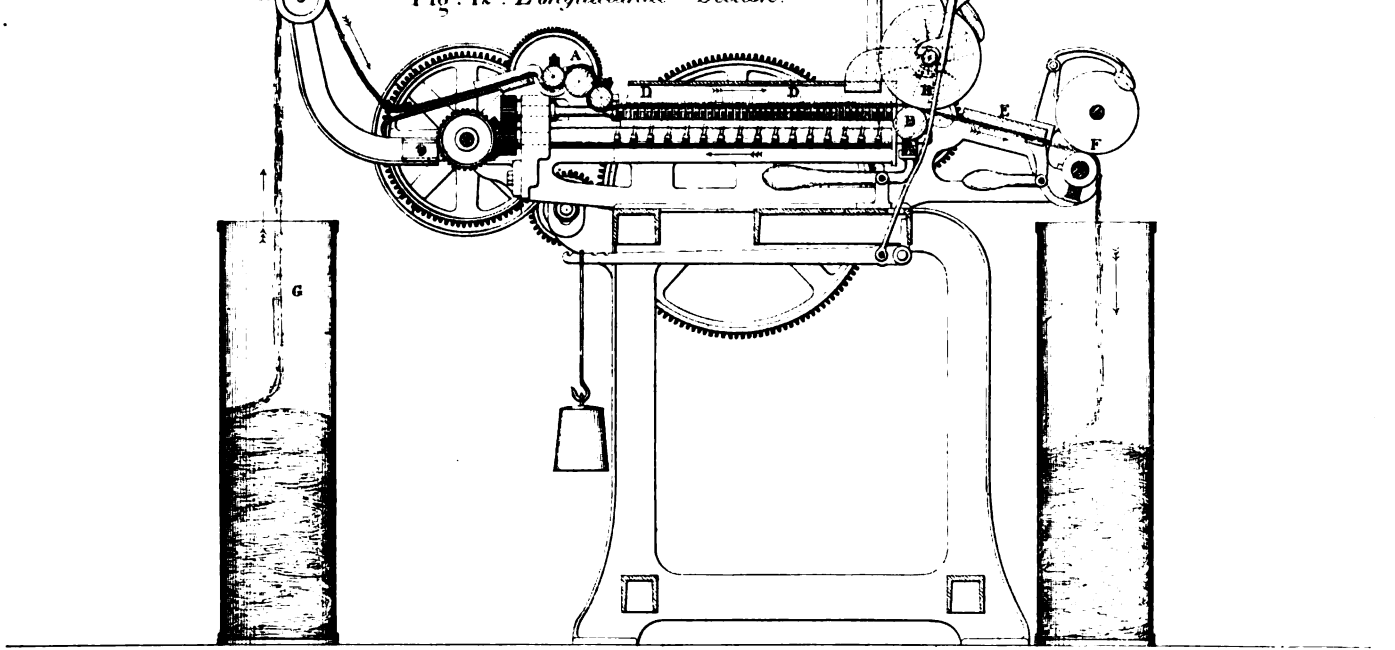
LONG-LINE ROVING FRAME.

Fig. 13. *End Elevation.*



Scale 1/16th

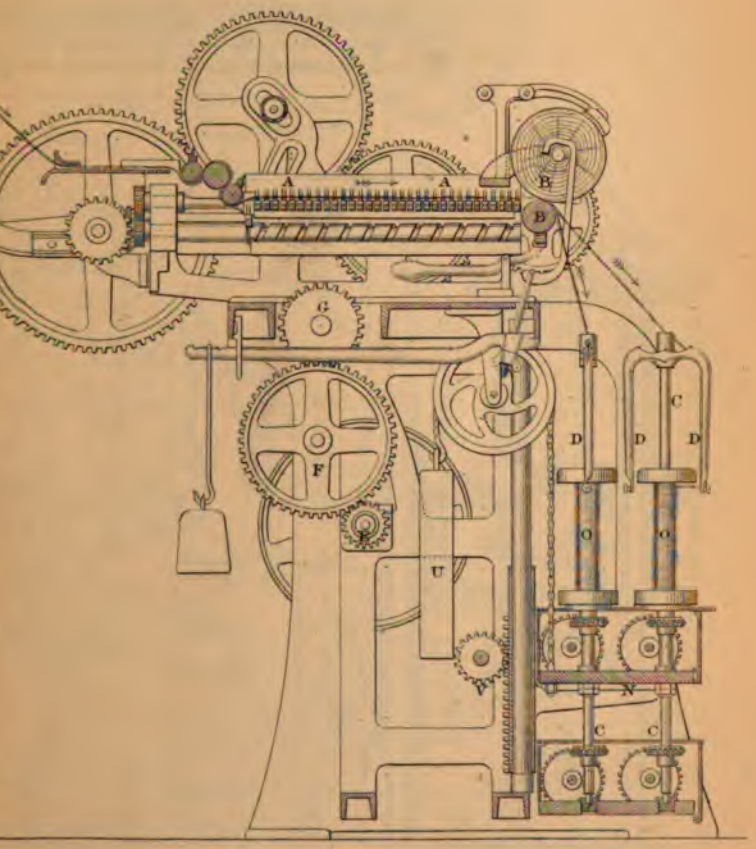
0 10 20 30 40 50 *Inches*



(Proceedings Inst. M.E. 1865. Page 103.) Scale 1/16th. 10 5 0 10 20 30 40 50 Inches.

LONG-LINE ROVING FRAME.

Fig. 13. *End Elevation.*

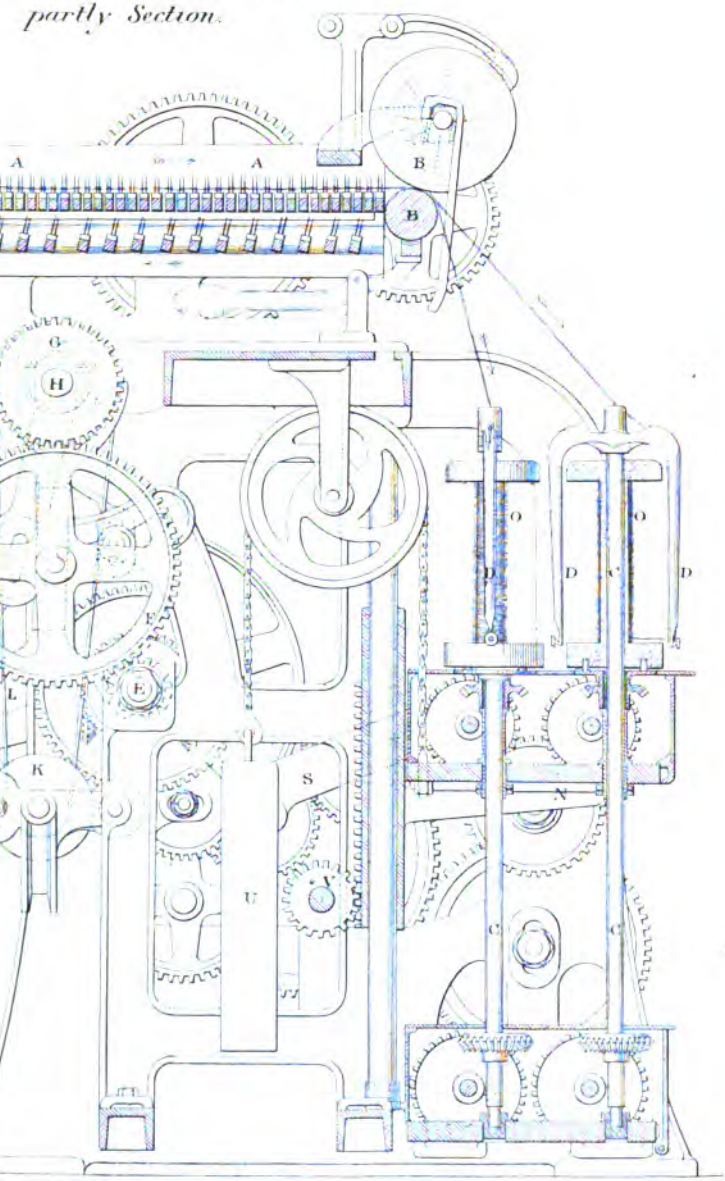


Scale 1/16th

0 10 20 30 40 50 *Inches*

LONG-LINE ROVING FRAME.

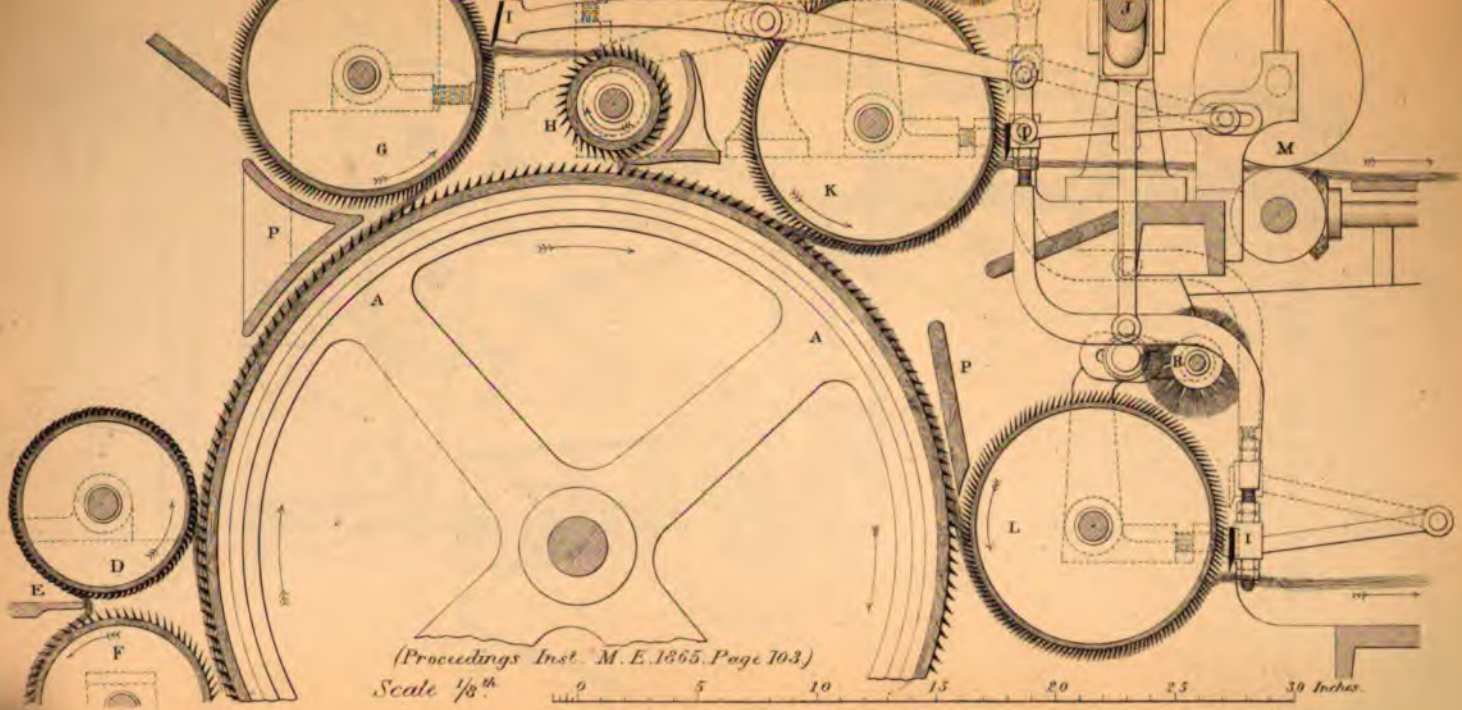
End Elevation enlarged, partly Section.



(Engineering Workshop Practice, Vol. 1, Textile Machinery, Spinning Machinery, Flax Machinery, Long-Line Roving Frame, End Elevation enlarged, partly Section, Plate 25, Page 103)

Scale 1/10th

0 10 20 30 Ins.


A
A
B
D
E
F
G
H
I
J
K
L
M
P
P
Q
(Proceedings Inst. M.E. 1865. Page 103.)
Scale 1/8th.
0
5
10
15
20
25
30 Inches.

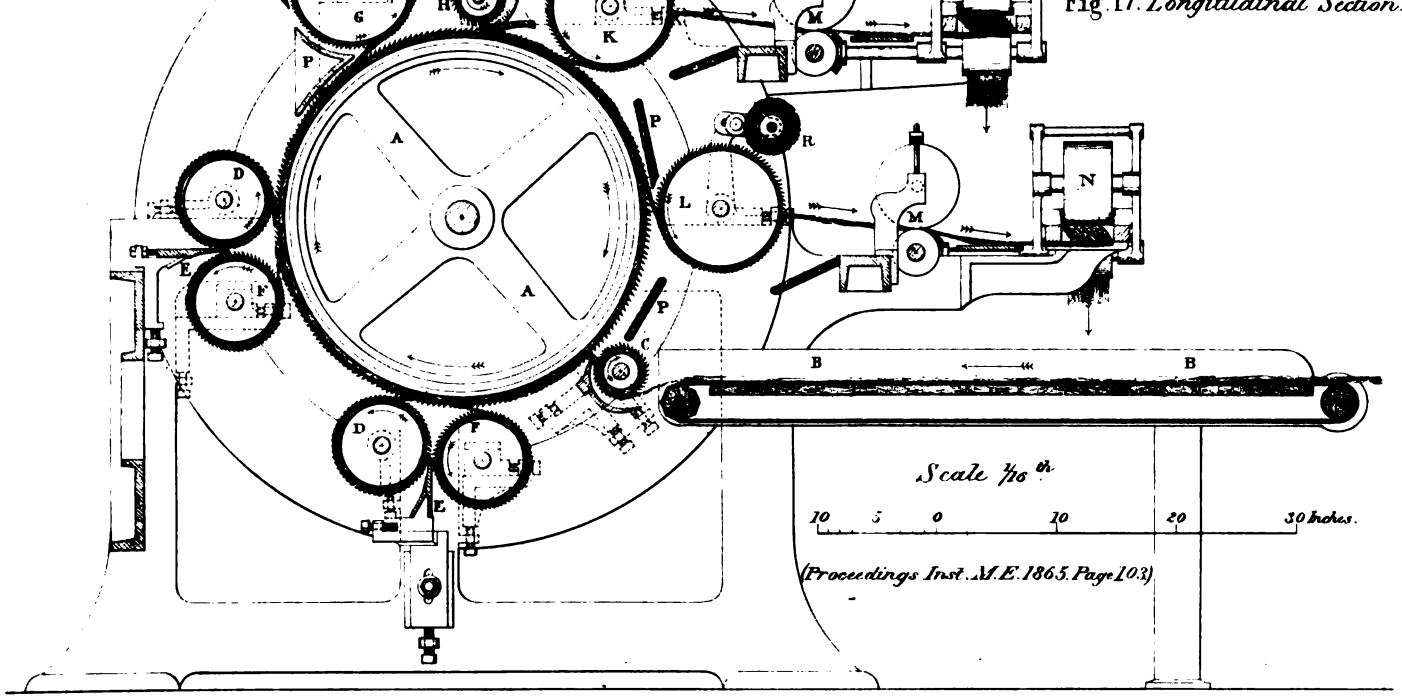
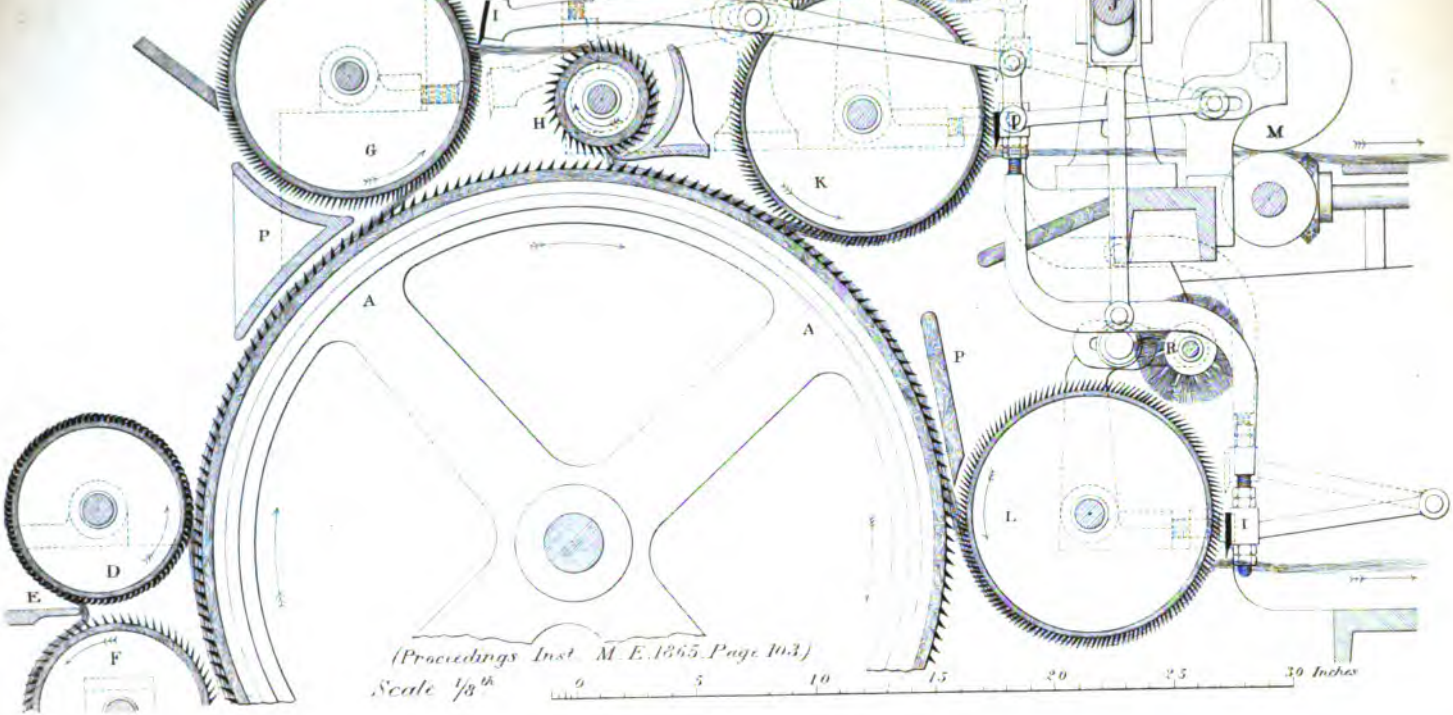
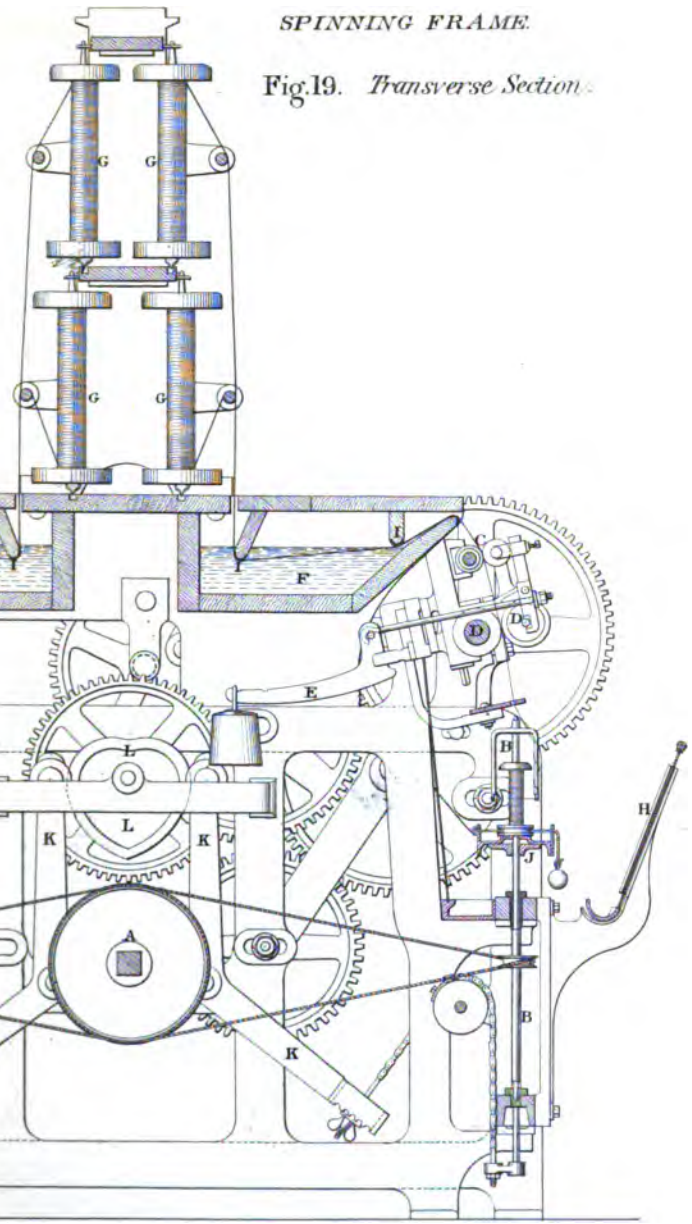


Fig. 17. Longitudinal Section.


G
H
I
K
M
P
A
A
P
R
L
I
D
E
F
(Proceedings Inst. M. E. 1865. Page 103)
Scale 1/8th
0
5
10
15
20
25
30 Inches

SPINNING FRAME.

Fig.19. *Transverse Section.*

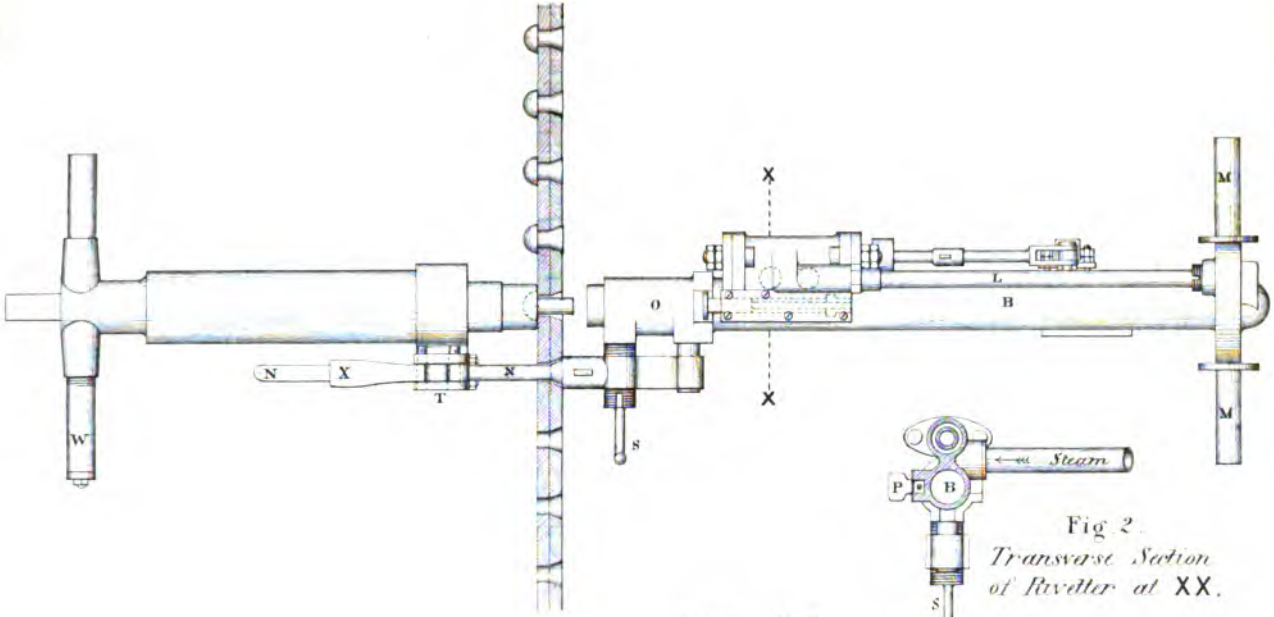


Scale 1/12th

5 0 10 20 30 *Inches.*

dings Inst. M.E. 1865. Page 103)

Fig. 1. *General Elevation of Rivetter and Dolly.*



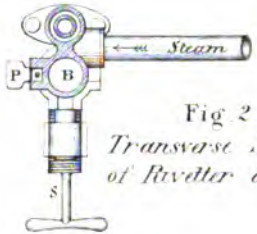


Fig. 2.
Transverse Section of Rivetter at XX.

Scale 1/8 in.

(Proceedings Inst. M.E. 1865. Page 129.)

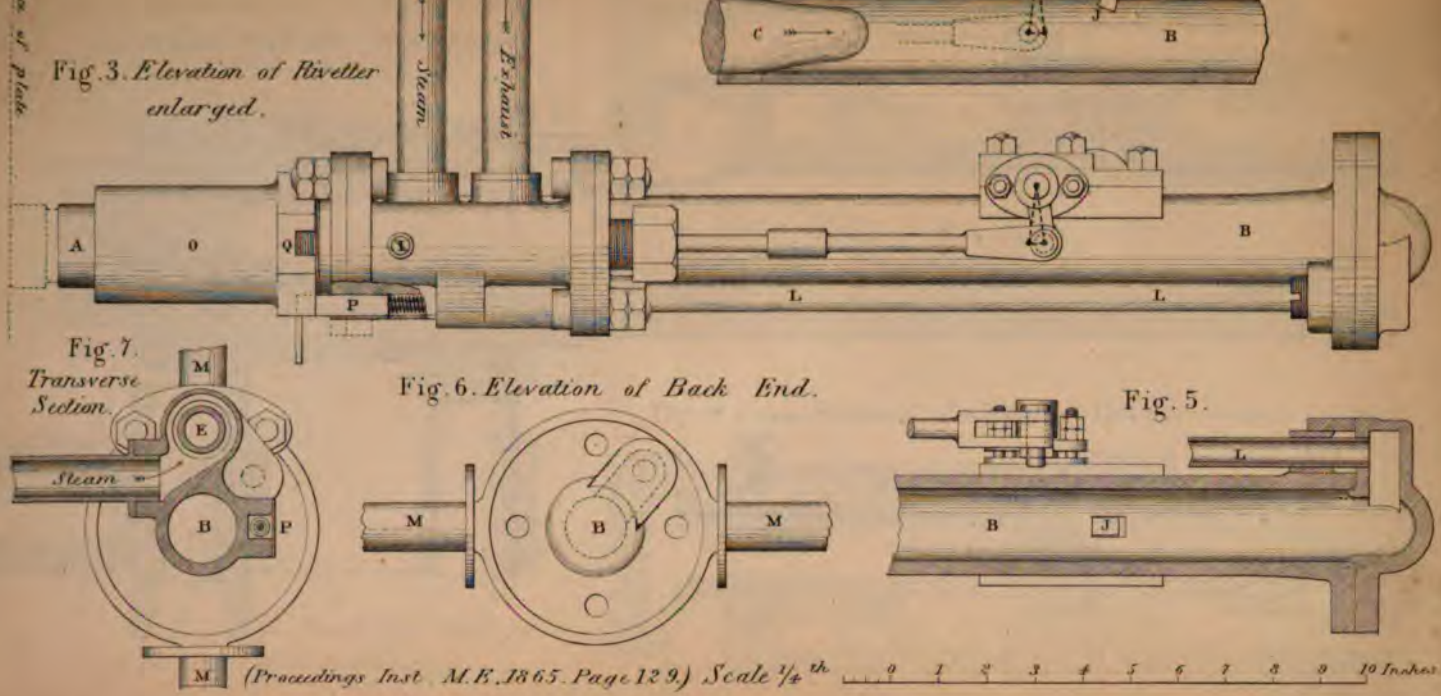


Fig. 3. *Elevation of Riveter enlarged.*

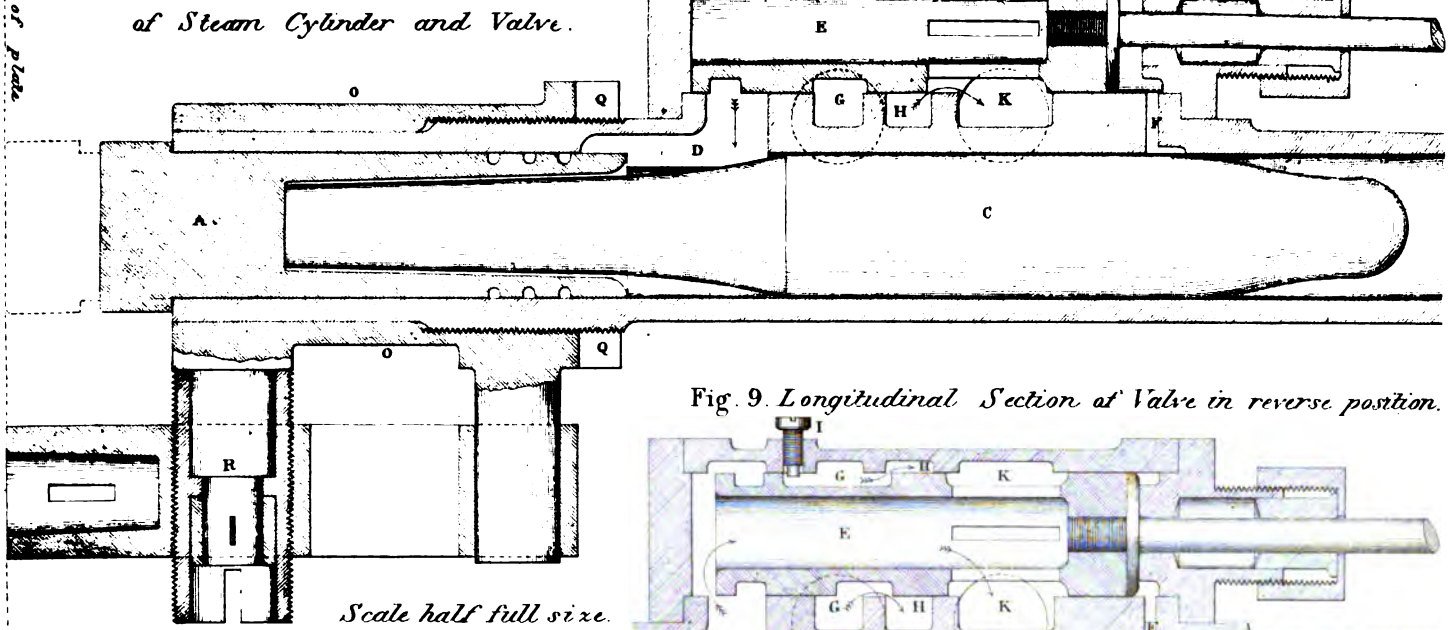
Fig. 7. *Transverse Section.*

Fig. 6. *Elevation of Back End.*

Fig. 5.

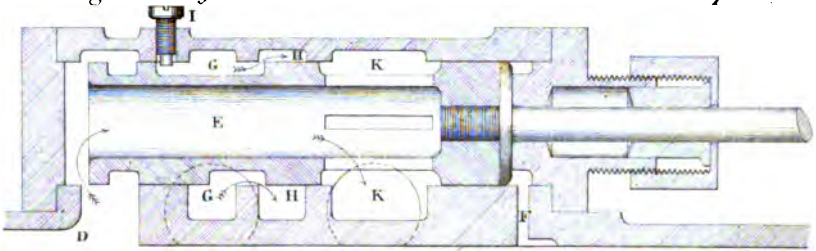
(Proceedings Inst. M.E. 1865. Page 129.) Scale 1/4th

of Steam Cylinder and Valve.



Scale half full size.

Fig. 9. *Longitudinal Section of Valve in reverse position.*



(Proceedings Inst. M.E. 1865. Page 129.)

Fig. 11.

Fig. 10. *Longitudinal Section of Spring Dolly for holding up the rivet.*

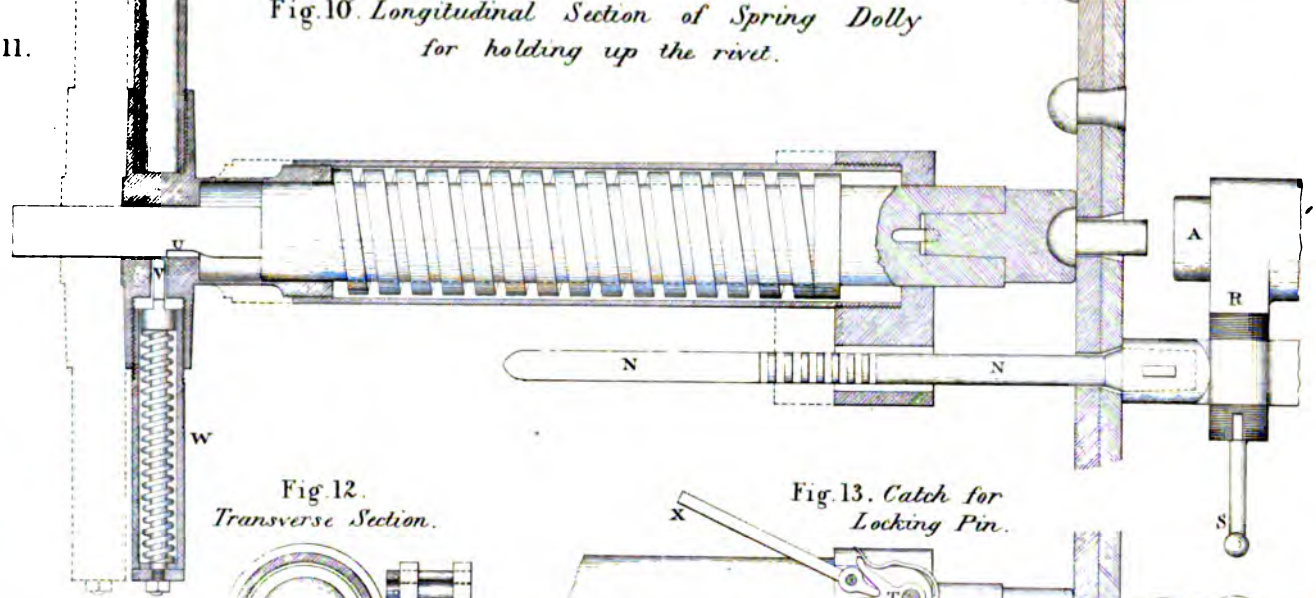
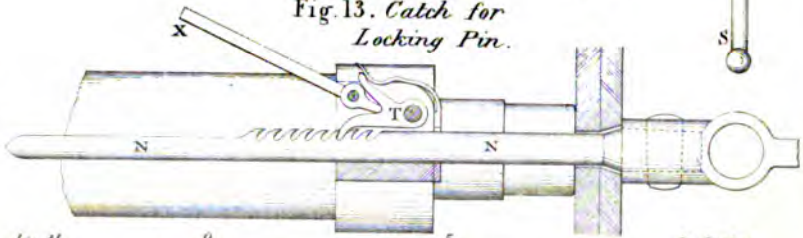


Fig. 12.
Transverse Section.

Fig. 13. *Catch for Locking Pin.*



(*Proceedings Inst. M.E. 1865. Page 129.*)

Scale 1/4th

0 5 10 Inches.

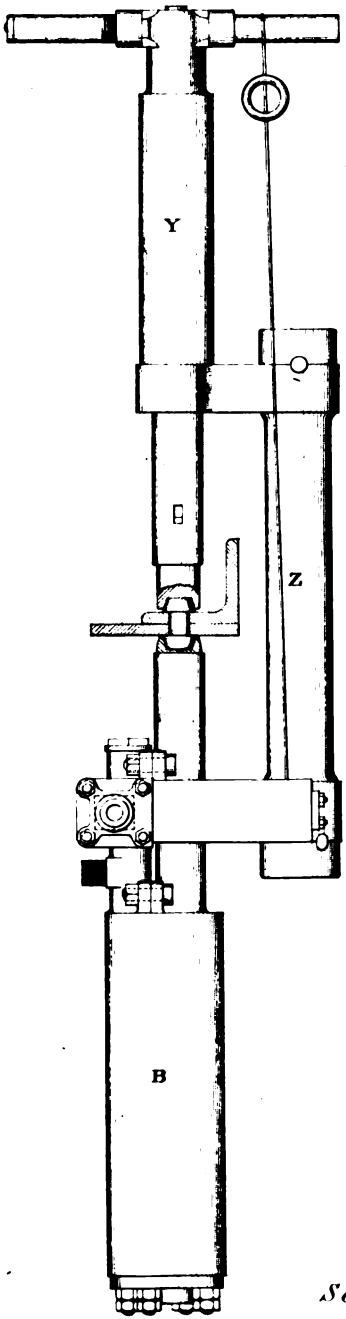


Fig. 14.
Elevation of Vertical Coupled Rivetter.

Scale 1/8th.

0 5 10 Inches.

(Proceedings Inst. M.E. 1865. Page 129)

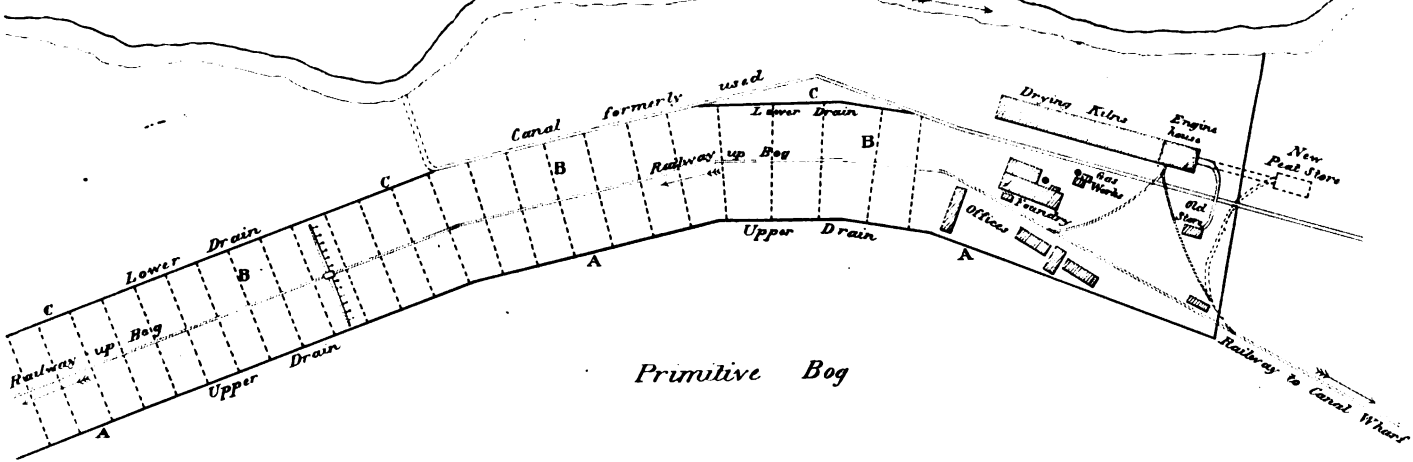
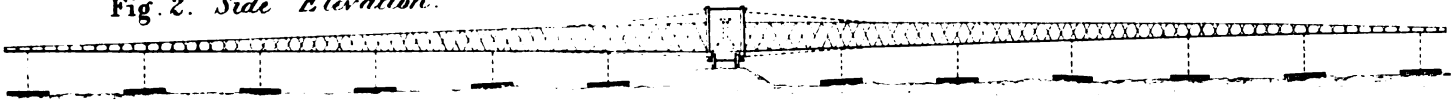


Fig 1 *General Plan of Derrylea Peat Works.*

(Proceedings Inst. M E 1865 Page 147) *Scale 1/6000th* 0 500 1000 1500 2000 Feet.

Fig. 2. *Side Elevation.*



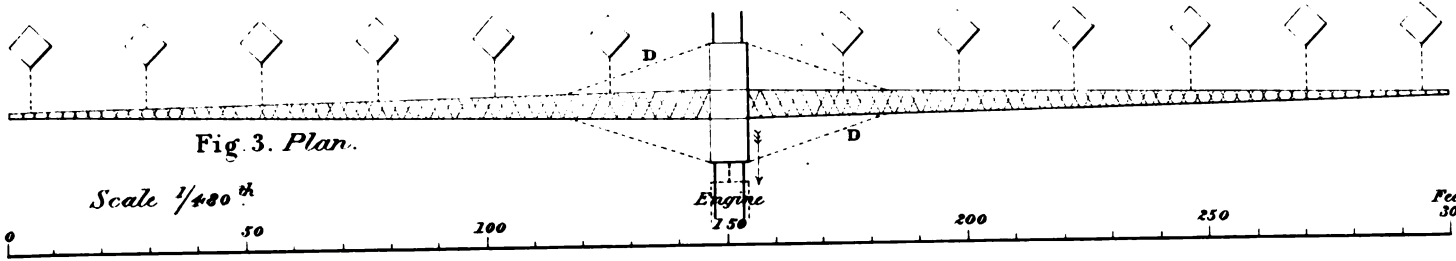
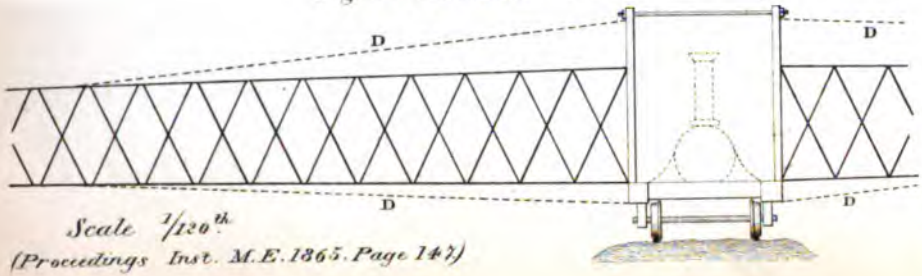


Fig. 3. *Plan.*

Scale 1/480th

Fig. 4. *Elevation of Girder at centre.*



Scale 1/120th

(Proceedings Inst. M.E. 1865. Page 147)

Fig. 5. *End Elevation.*

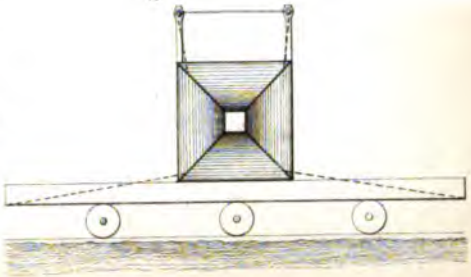


Fig. 6. *Side Elevation of Drying Kilns and Engine Room.*

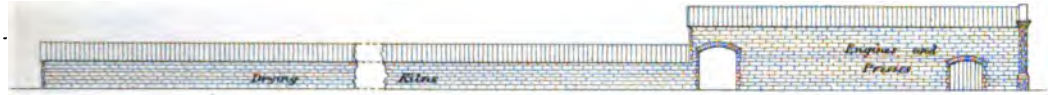


Fig. 7. *Transverse Section.*

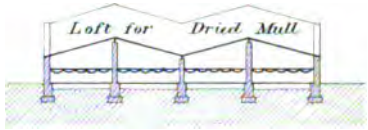
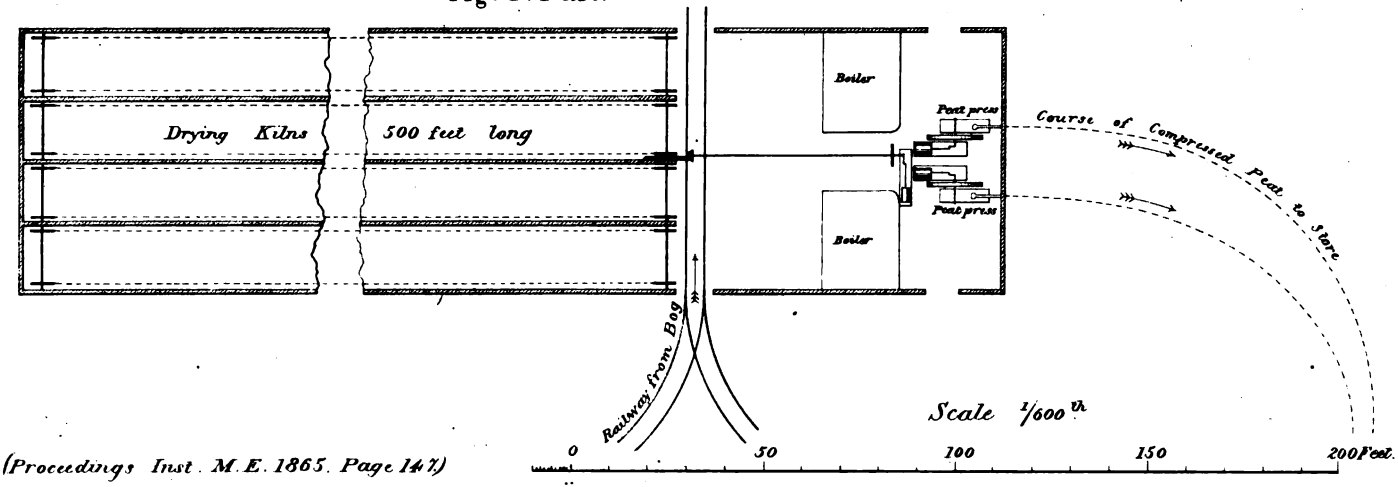


Fig. 8. *Plan.*



(Proceedings Inst. M.E. 1865. Page 147)

Fig. 9 *Longitudinal Section of Drying Kiln, enlarged.*

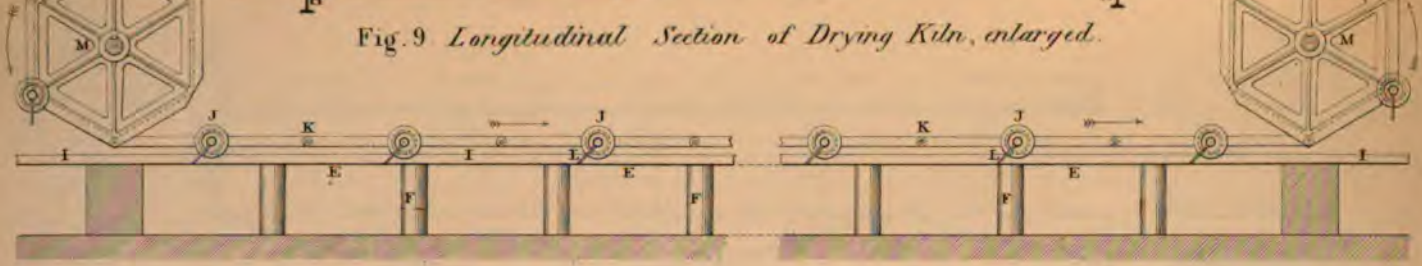
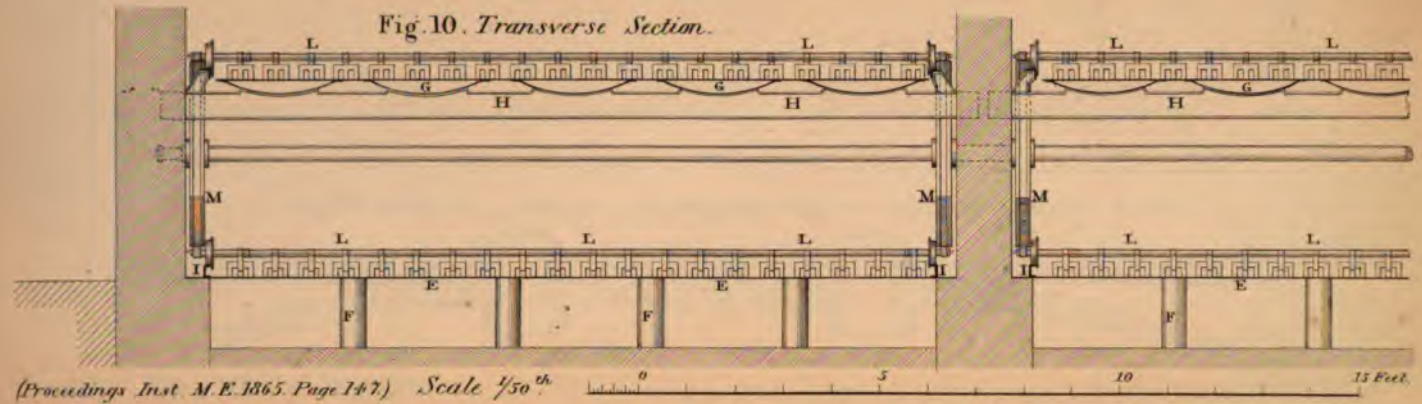
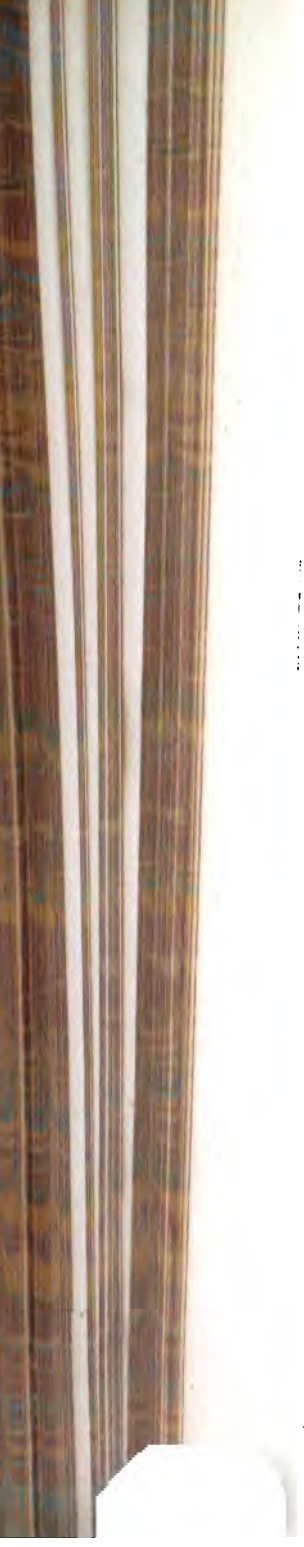


Fig. 10. *Transverse Section.*



(Proceedings Inst. M.E. 1865. Page 147.) *Scale 1/50th*



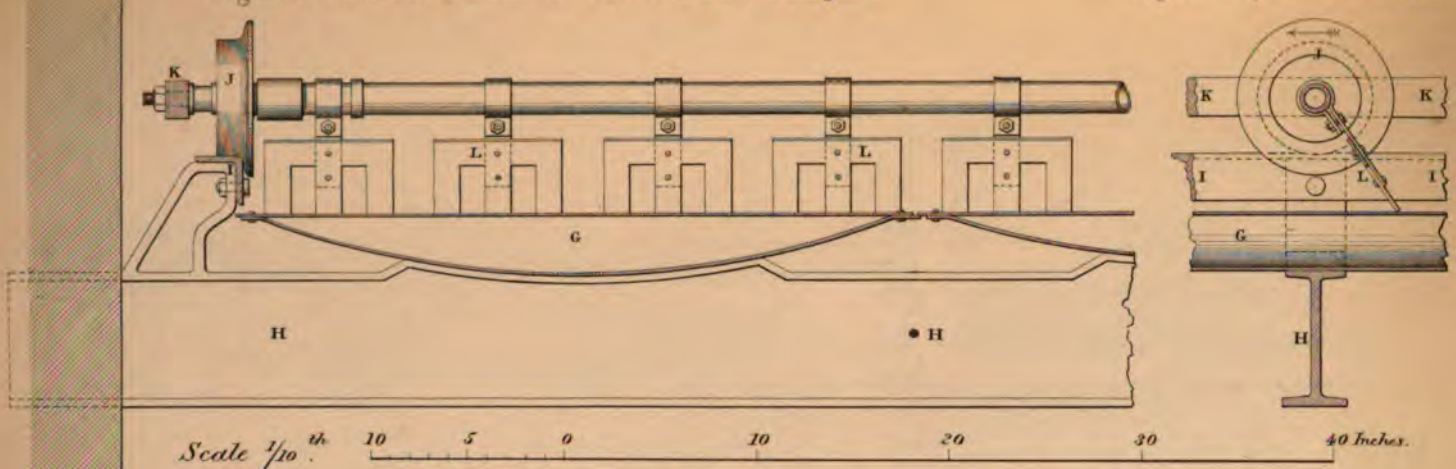


Fig. 13. *Full-size Section showing Overlap at edges of Steam Tables.*

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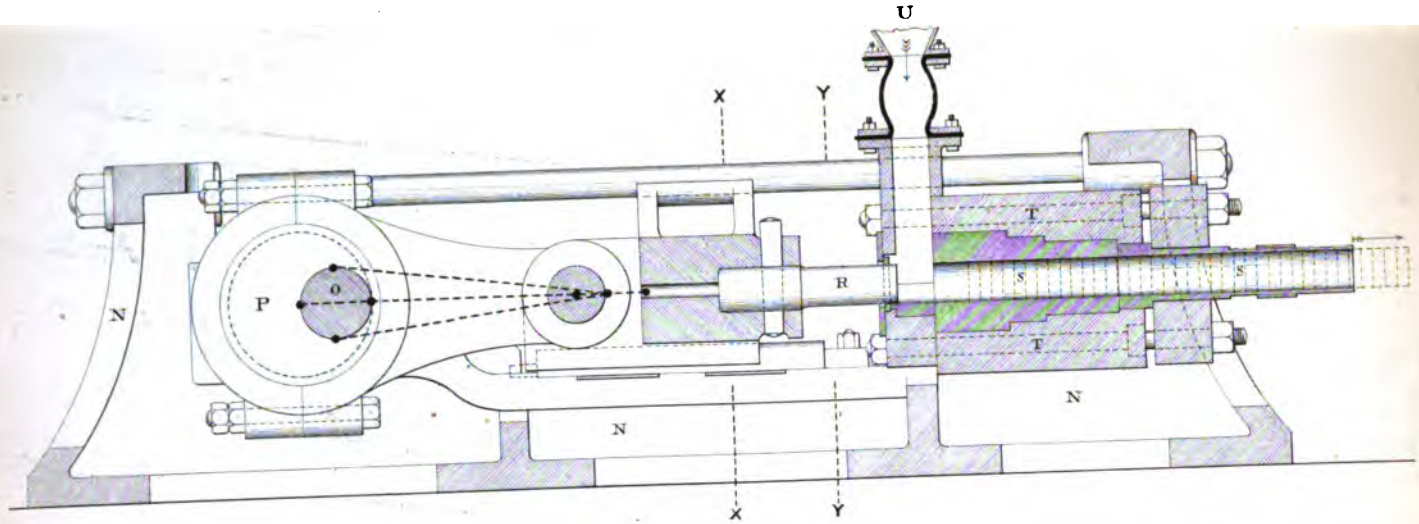
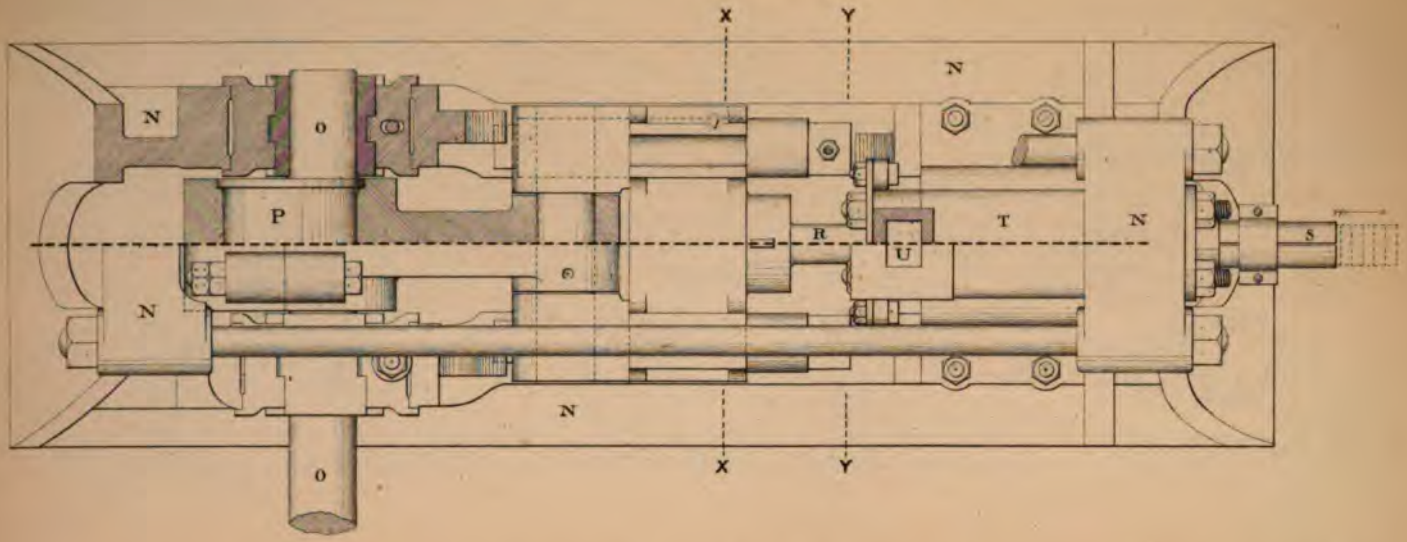
Fig. 14. *Longitudinal Section of Peat Press.*



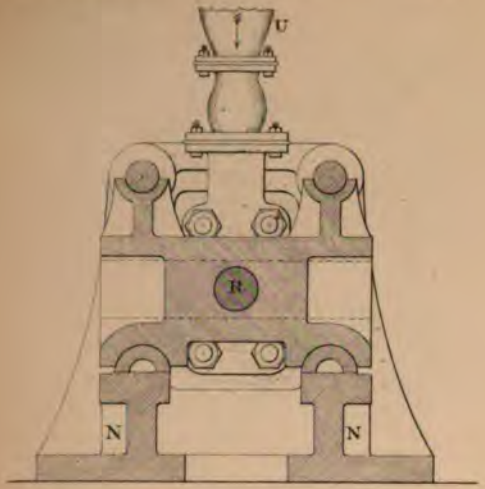
(Proceedings Inst. M.E. 1865. Page 147) *Scale* 1/20th. 10 5 0 10 20 30 40 50 Inches.

Fig. 15. *Plan of Peat Press, partly in Section.*

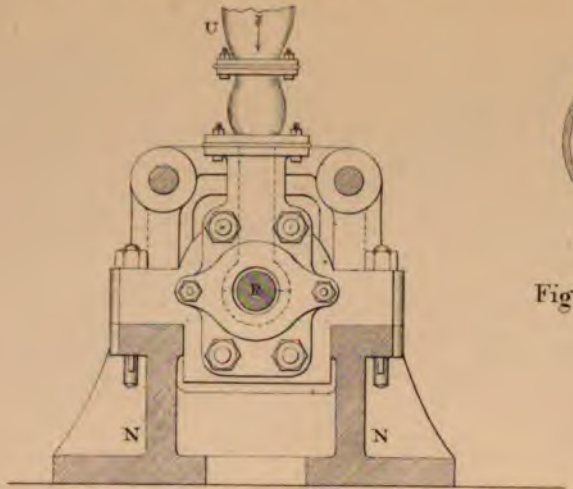


(Proceedings Inst. M.E. 1865. Page 147) *Scale 1/20th* 10 5 0 10 20 30 40 50 Inches.

of Peat Press at XX (Figs. 14 and 15)



of Peat Press at YY (Figs. 14 and 16.



on nozzle of Tube.

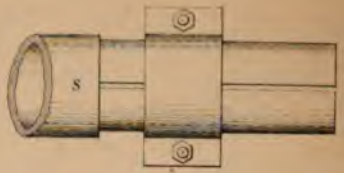


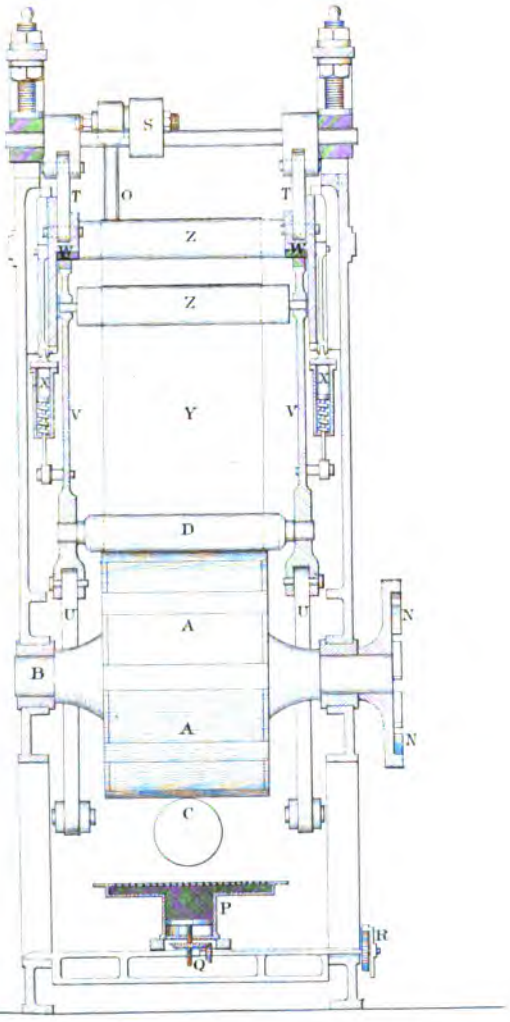
Fig. 19. *Transverse Section of nozzle*

Scale 3/10 th.

(*Proceedings Inst. M.E. 1865. Page 147*)

Scale 1/20 th. 10 5 0 10 20 30 40 50 Inches.

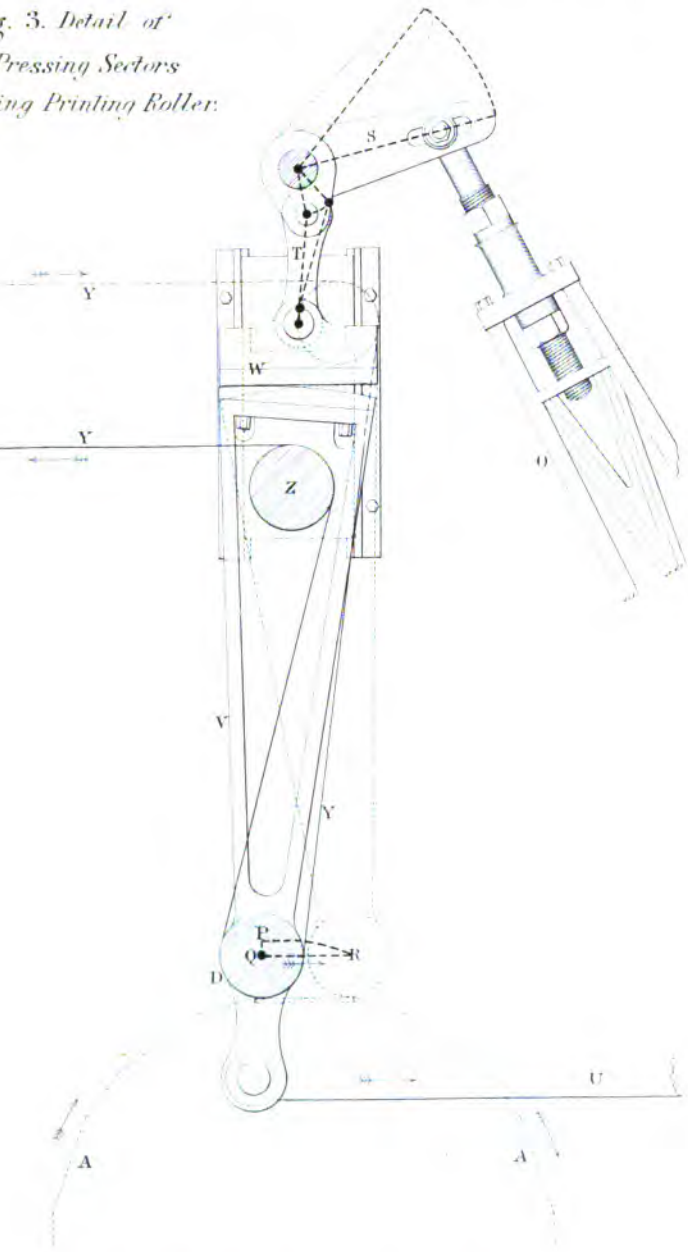
Fig. 2. *Vertical Section.*



ceedings Inst. M.E. 1865. Page 166. *Scale* $^1/_{24}$*th*

5 0 10 20 30 40 50 60 70 *Inches.*

g. 3. Detail of
Pressing Sectors
ing Printing Roller.

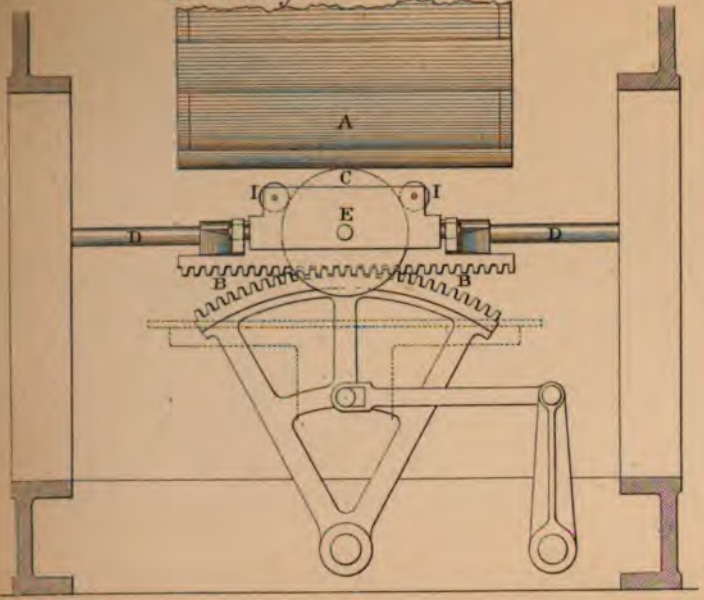


edings Inst. ME. 1865. Page 166)

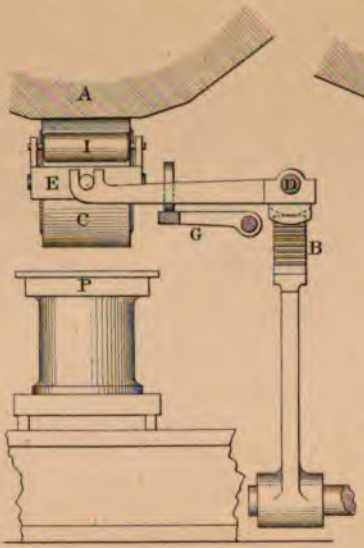
Scale $\frac{1}{12}$ *th*

5 0 10 20 30 *Inches.*

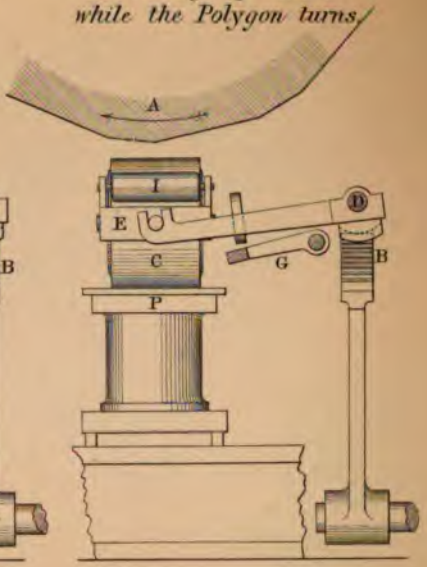
for inking the Polygon.



showing Roller raised for inking the Polygon.



showing Roller lowered for taking up Ink, while the Polygon turns.



(Proceedings Inst. M.E. 1865. Page 166.) Scale $^{1}/_{12}$th

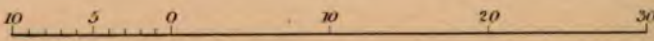
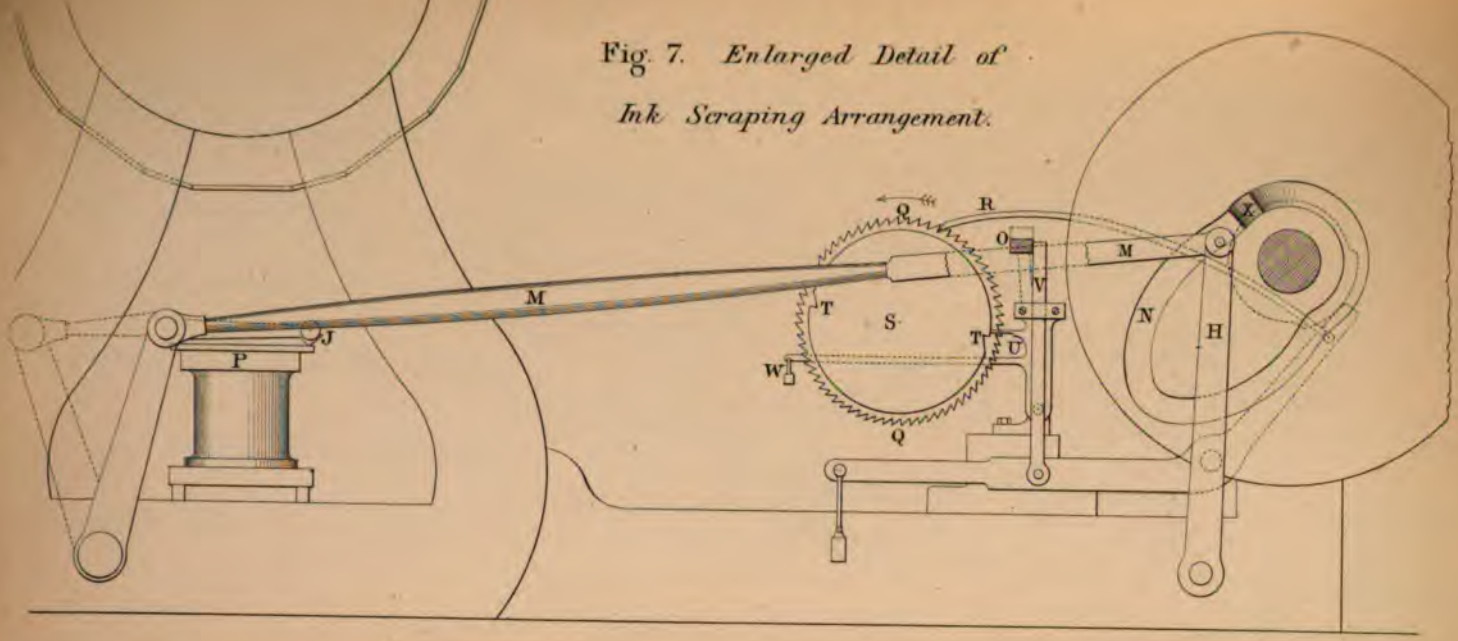
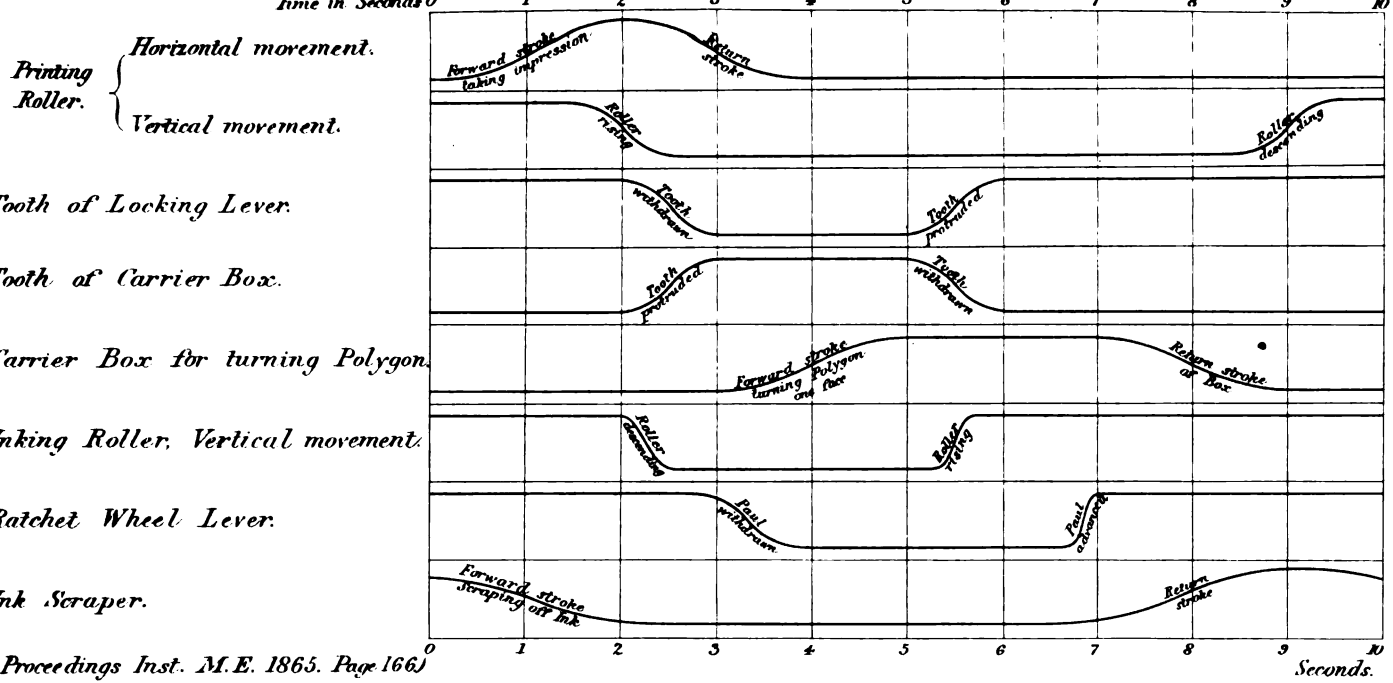


Fig. 7. *Enlarged Detail of Ink Scraping Arrangement.*



(Proceedings Inst. M.E. 1865. Page 166) *Scale* $^{1}/_{12}^{th}$

10 5 0 10 20 30 Inches.



(Proceedings Inst. M.E. 1865. Page 166)

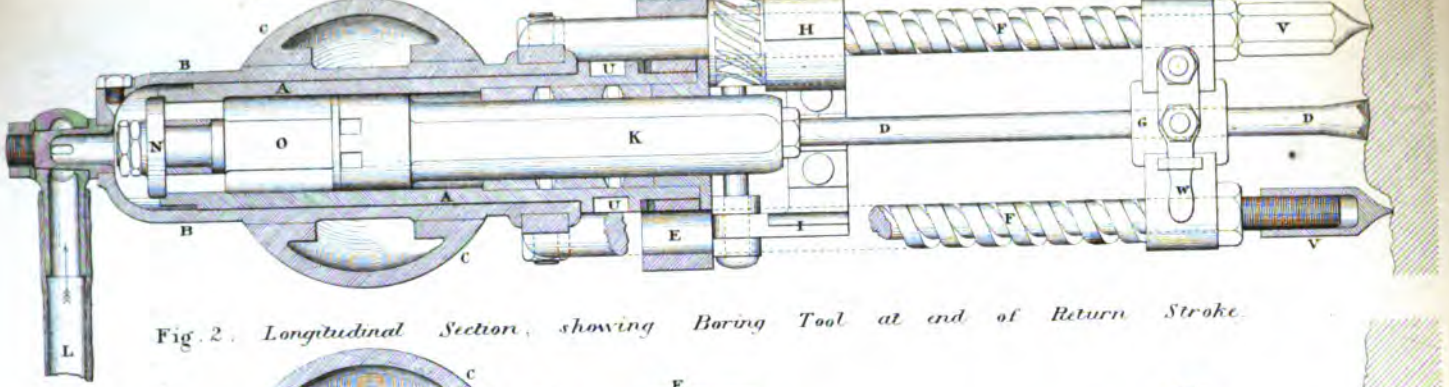
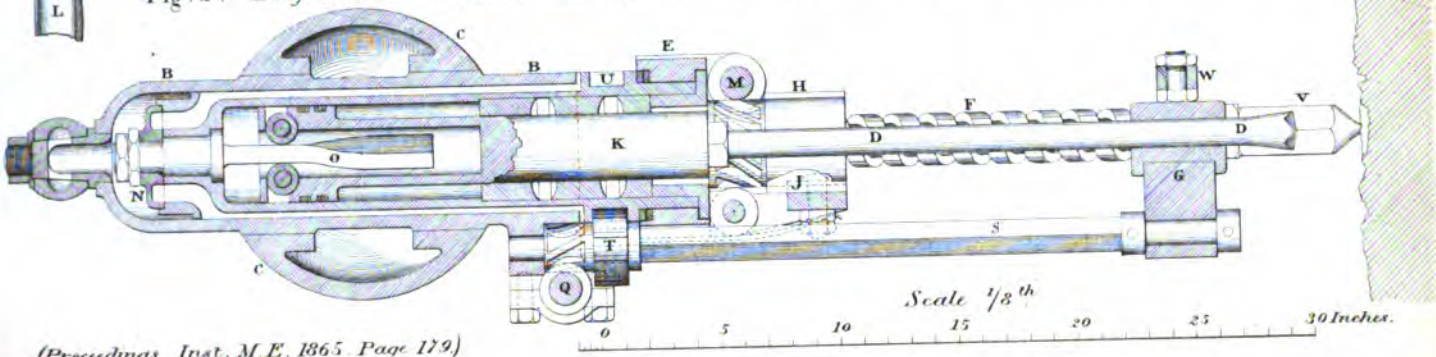


Fig. 2. *Longitudinal Section, showing Boring Tool at end of Return Stroke.*



(Proceedings Inst. M.E. 1865 Page 179)

Fig 3 *Sectional Plan, showing Working Cylinder advanced as the Hole progresses.*

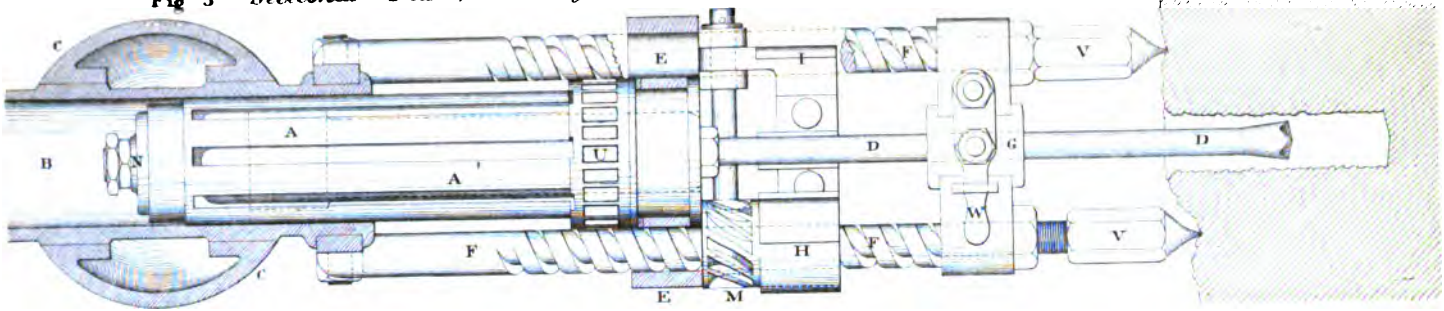
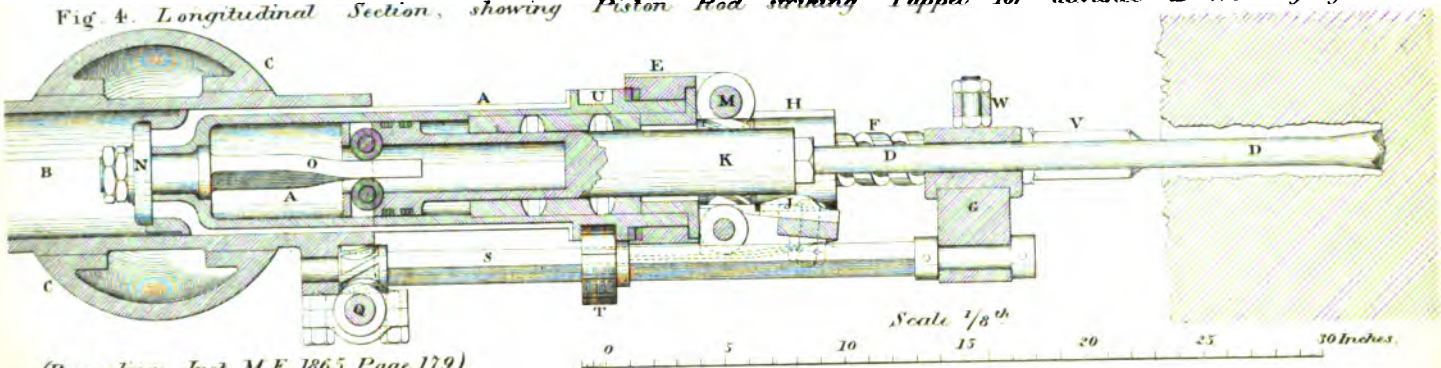


Fig 4. *Longitudinal Section, showing Piston Rod striking Tappet for advance of Working Cylinder.*



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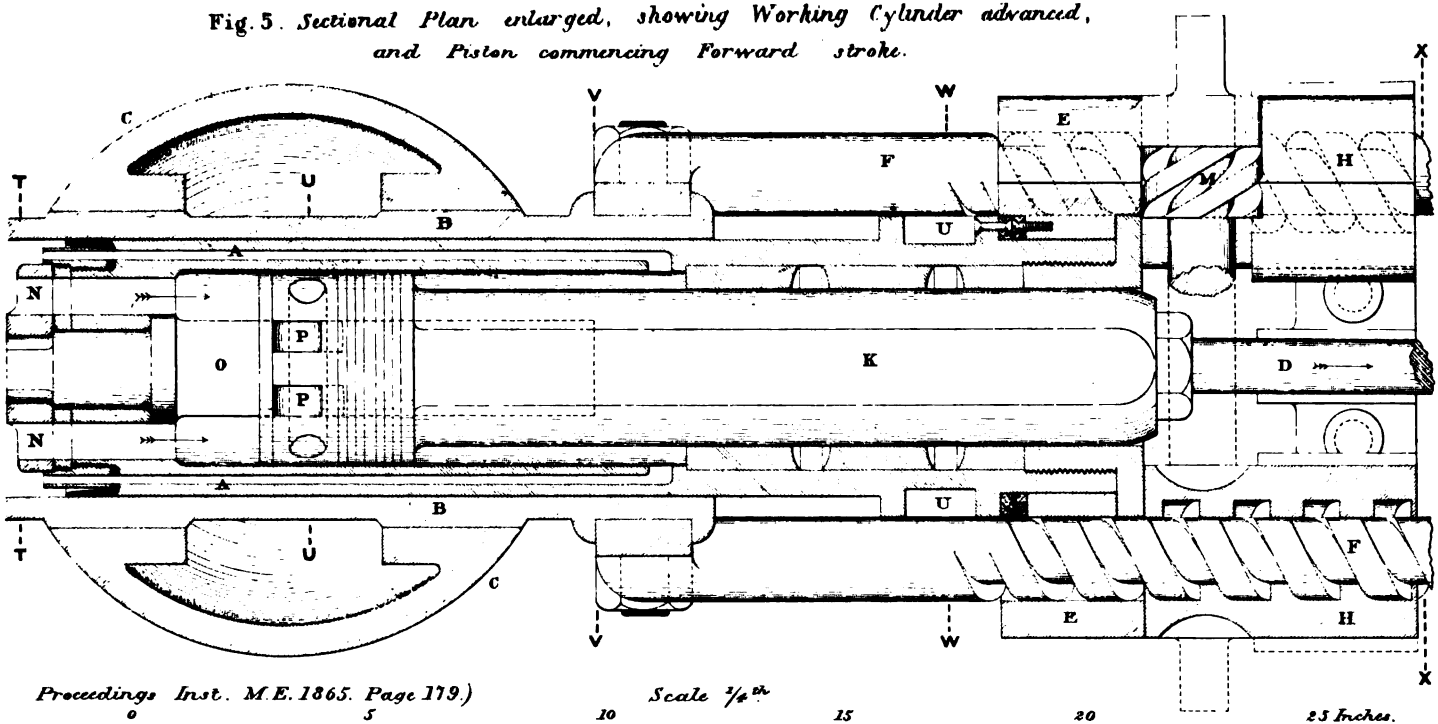
ROCK BORING MACHINE.

Plate 51.

Fig. 5. *Sectional Plan enlarged, showing Working Cylinder advanced, and Piston commencing Forward stroke.*



Proceedings Inst. M.E. 1865. Page 179.)

Scale 1/2 in.

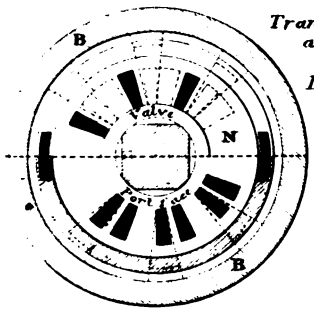
0 5 10 15 20 25 Inches.

ROCK BORING MACHINE. *Plate 52.*

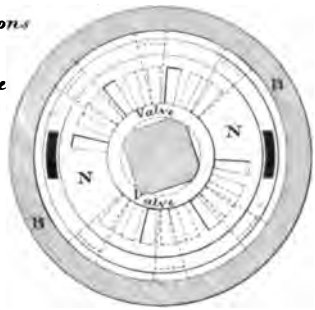
Transverse Sections enlarged (looking forwards).

Fig. 6. *Air Ports Open for Forward stroke.*

Fig. 7. *Air Ports Closed for Return stroke.*



Transverse Sections at **TT** *(Fig. 5) showing Disc Air Valve and Ports.*



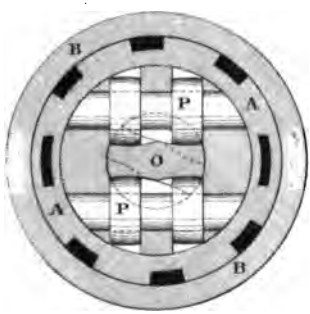
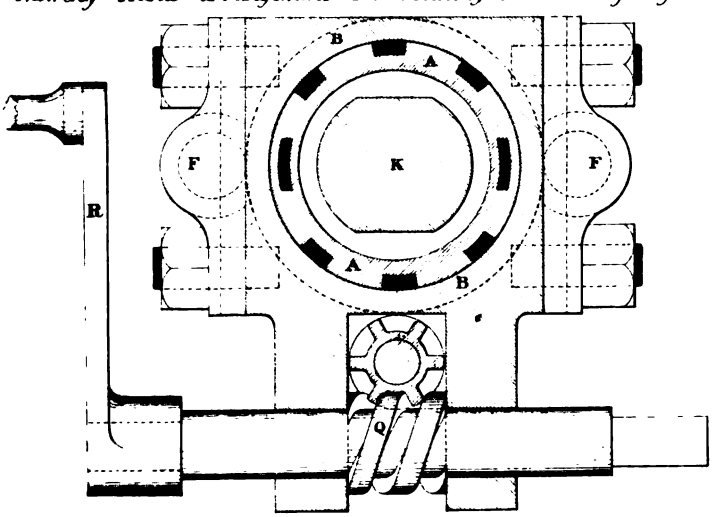


Fig. 8. *Transverse Section at* **UU** *(Fig. 5.) showing Rollers and Cam for turning Air Valve.*

Fig. 9. *Transverse Section at* **VV** *(Fig. 5.) showing Hand arrangement for rotating the Working Cylinder.*



(Proceedings Inst M. E 1865. Page 119)

Scale 1/8th

0 1 2 3 4 5 6 7 8 9 10 11 12 Inches

Transverse Sections enlarged (looking backwards).

Fig. 10. *Transverse Section at* **WW** *(Fig. 5.)*
showing Hand arrangement for rotating the Working Cylinder.

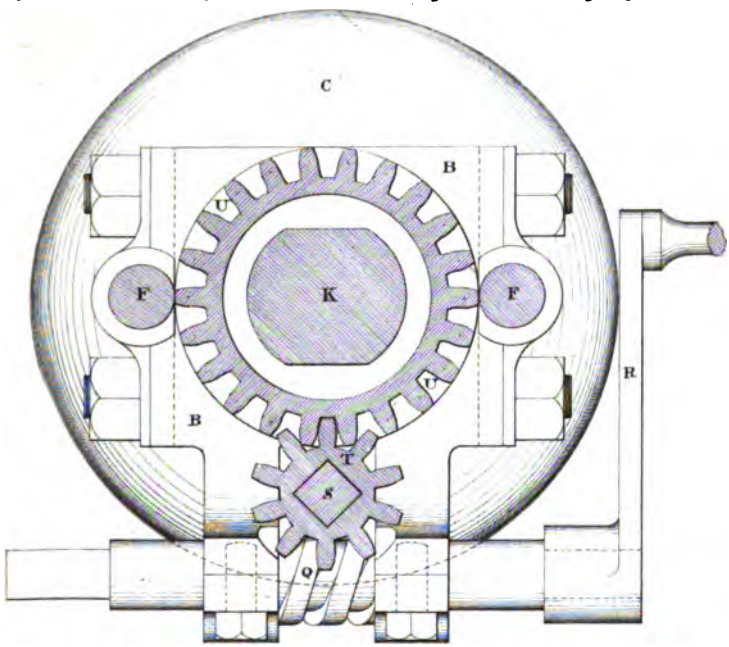
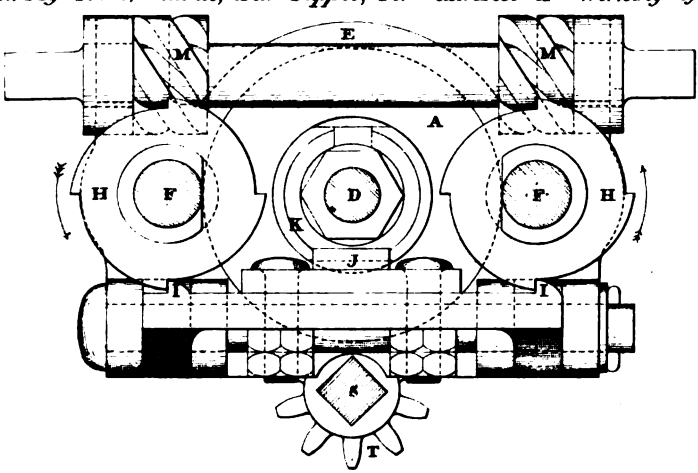


Fig 11. *Transverse Section at* **XX** *(Fig. 5.)*
showing Nuts, Catches, and Tappet, for advance of Working Cylinder.



(Proceedings Inst. M.E. 1865. Page 179.) *Scale* 1/4 in.

0 1 2 3 4 5 6 7 8 9 10 11 12 Inches.

ROCK BORING MACHINE. *Plate 54.*

Detail of Boring Tools, and mode of Fixing.

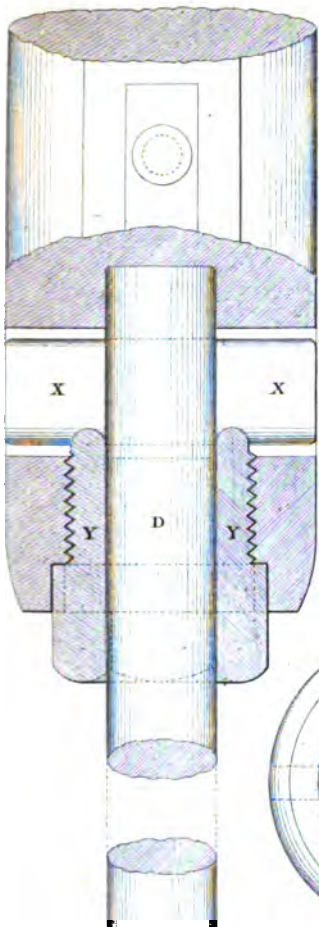
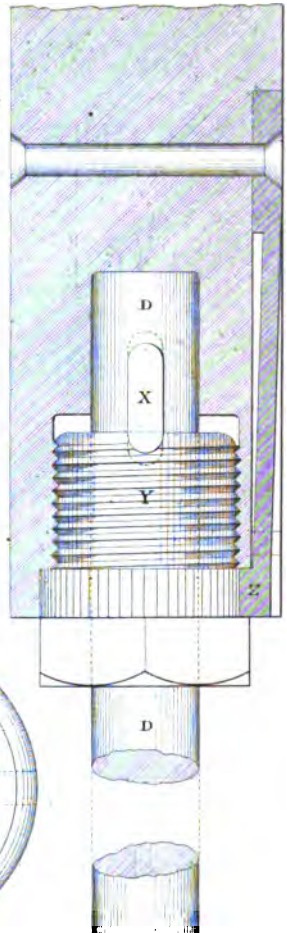


Fig. 12.

Fig. 13.



Mode of Fixing the Boring Tool.

Fig. 14.
End View

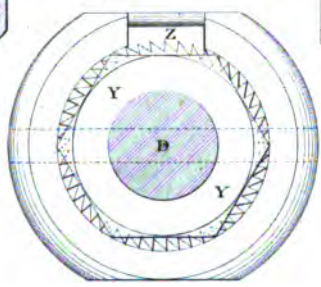


Fig. 15. *Nose Tool for commencing hole.*

Fig. 17. *Chisel Tool for completing hole.*

Fig. 19.

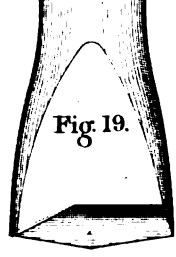


Fig. 16.

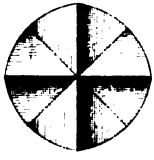


Fig. 18.

Fig. 20.

(Proceedings Inst. M.E. 1865. Page 179.) *Scale half full size.*

Sections of Roundwood Tunnel, showing Boring Machine in working position, with Frame and Carriage.

Fig. 21. *Longitudinal Section.*

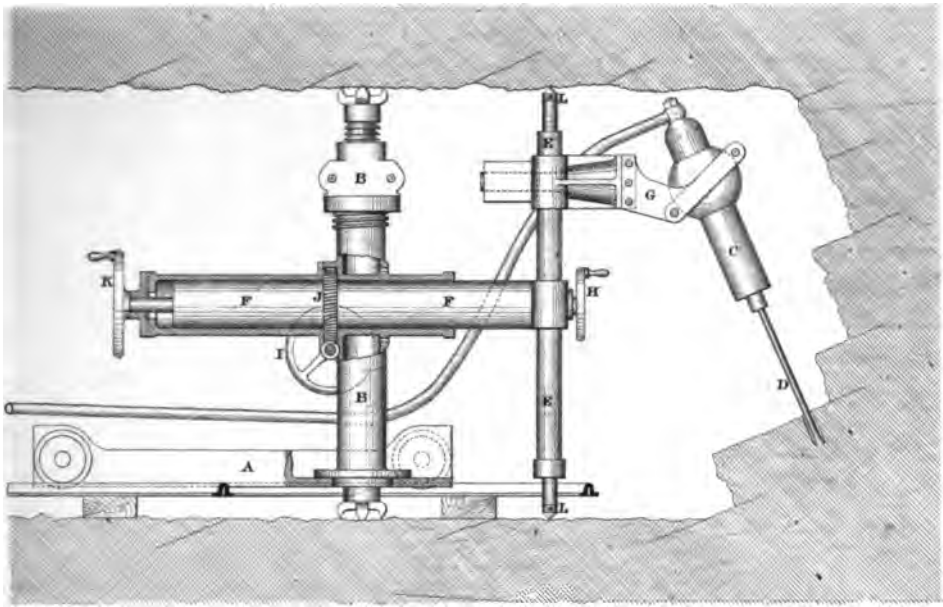
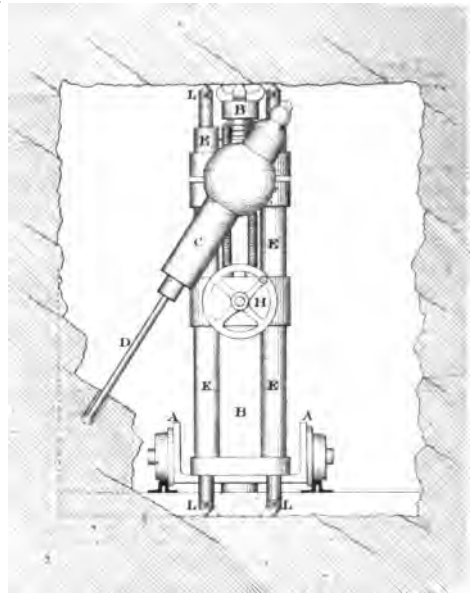


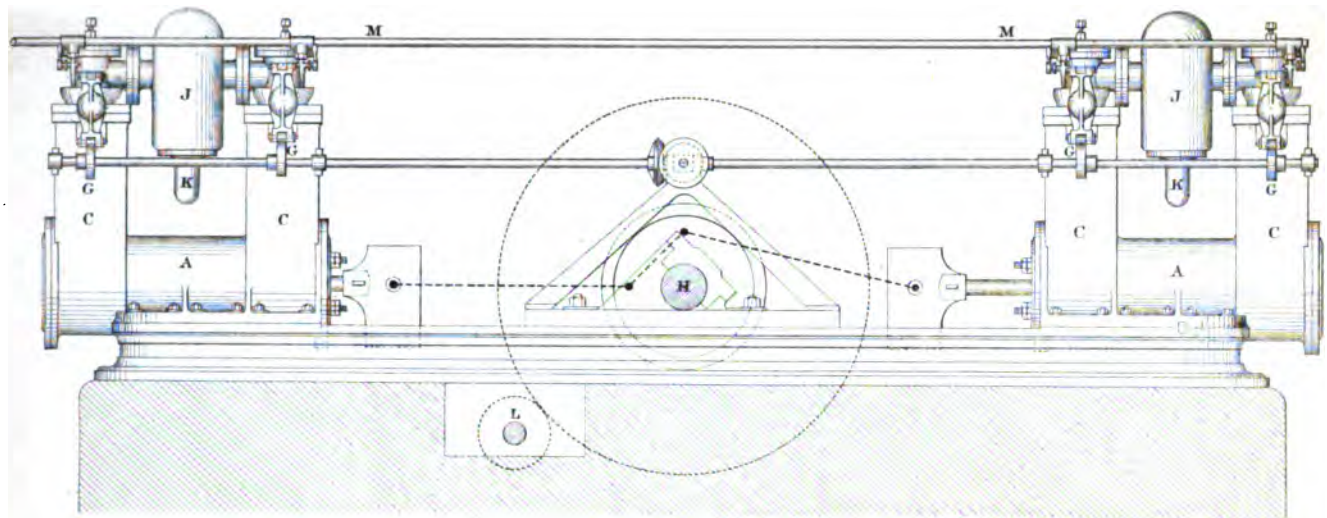
Fig. 22. *Transverse Section.*



(Proceedings Inst. M.E. 1865. Page 179.) *Scale* 1/32nd 0 1 2 3 4 5 6 7 8 9 10 Feet.

Air Compressing Engine.

Fig. 23. *Side Elevation.*



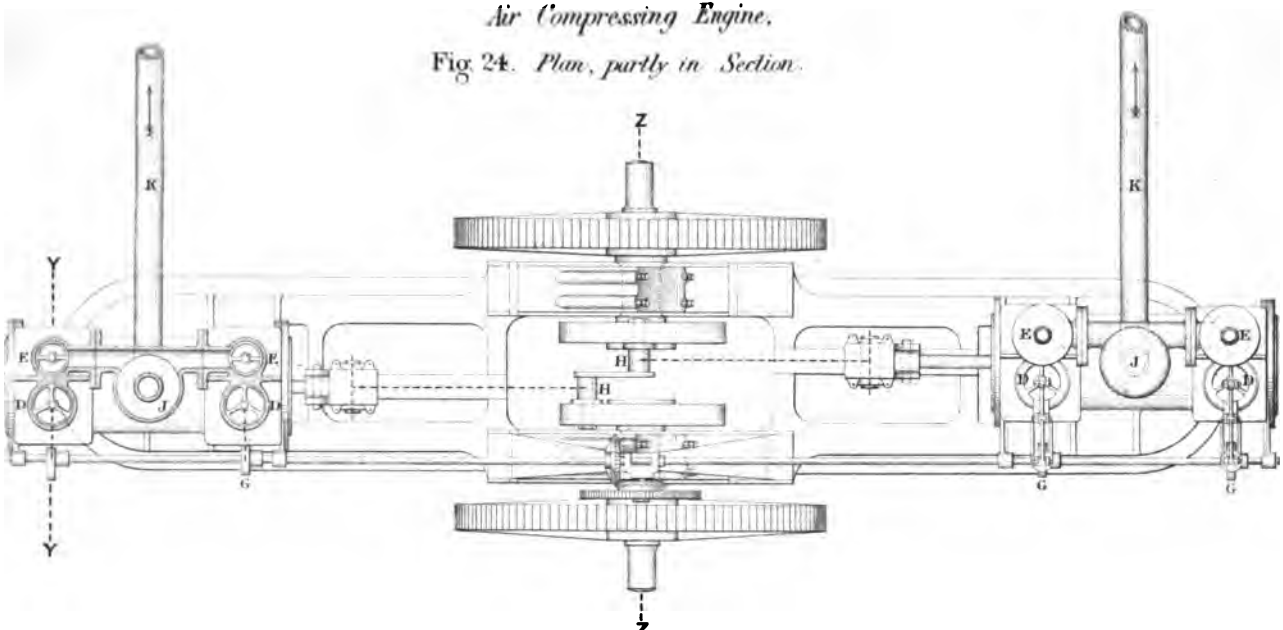
Scale 1/32nd

0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1865. Page 179.)

Air Compressing Engine.

Fig. 24. *Plan, partly in Section.*



Scale 1/32nd

(Proceedings Inst. M.E. 1865. Page 172.)

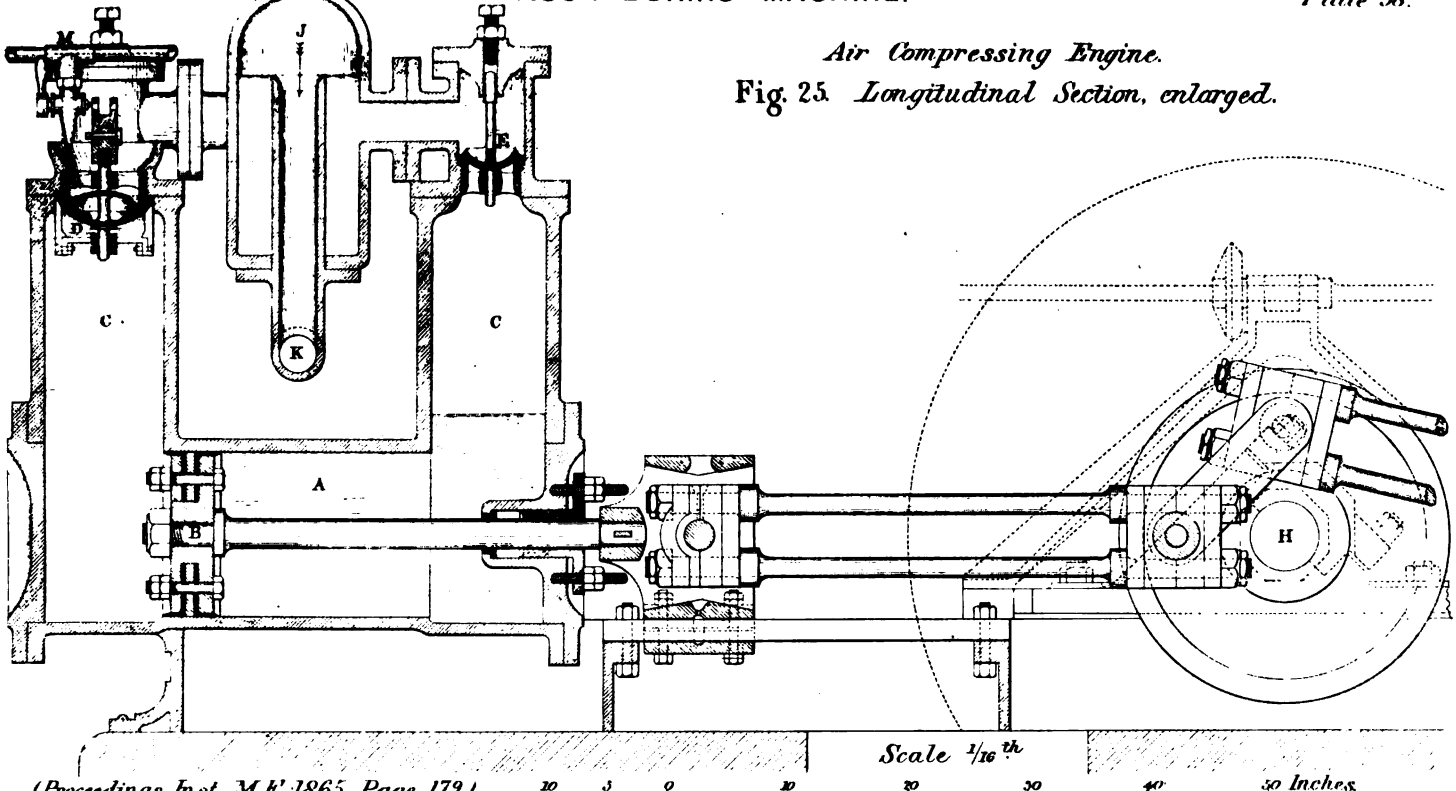
0 1 2 3 4 5 6 7 8 9 10 *Feet.*

ROCK BORING MACHINE.

Plate 38.

Air Compressing Engine.

Fig. 25. *Longitudinal Section, enlarged.*



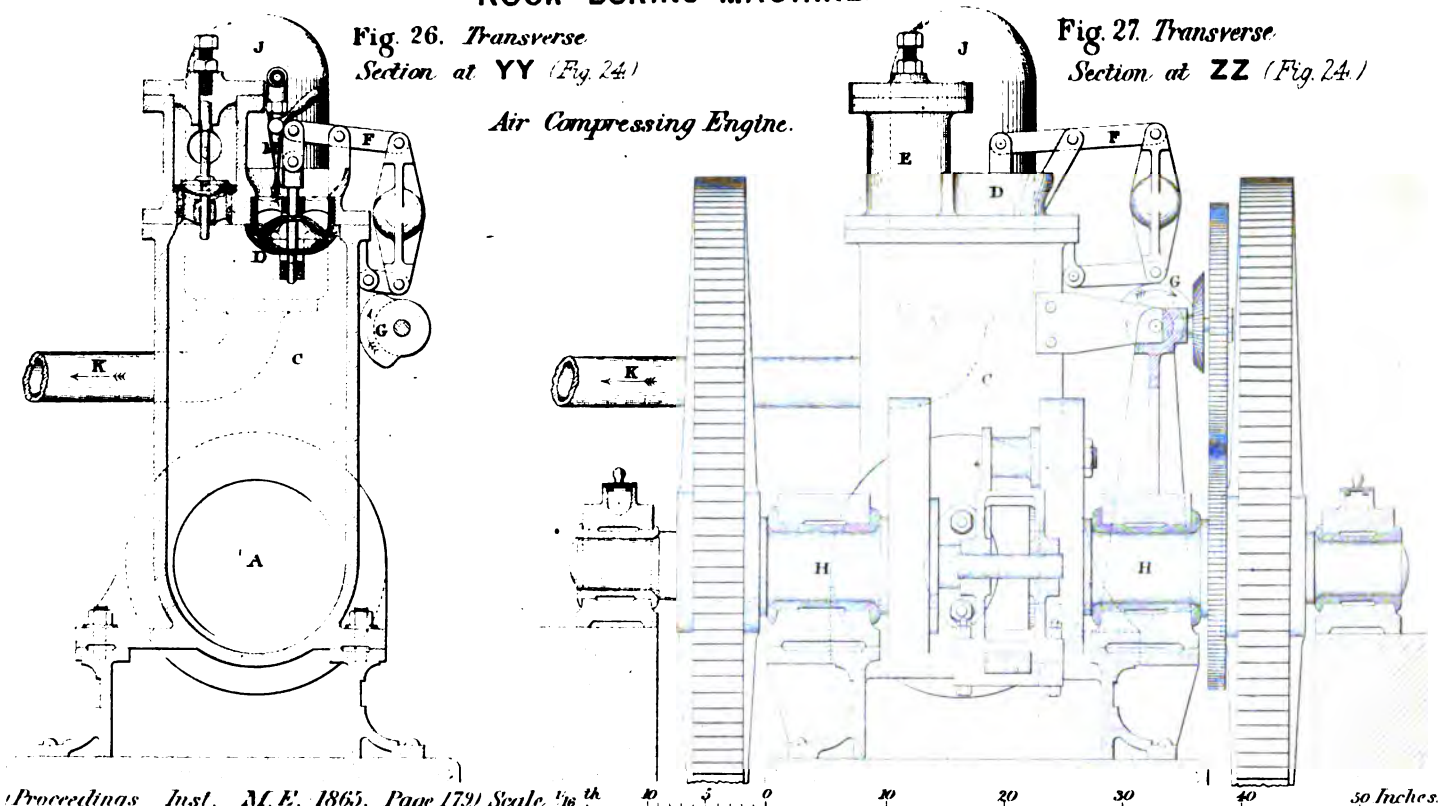
(Proceedings Inst. M.E. 1865. Page 179.)

ROCK BORING MACHINE.

Fig. 26. *Transverse Section at* **YY** *(Fig. 24.)*

Fig. 27. *Transverse Section at* **ZZ** *(Fig. 24.)*

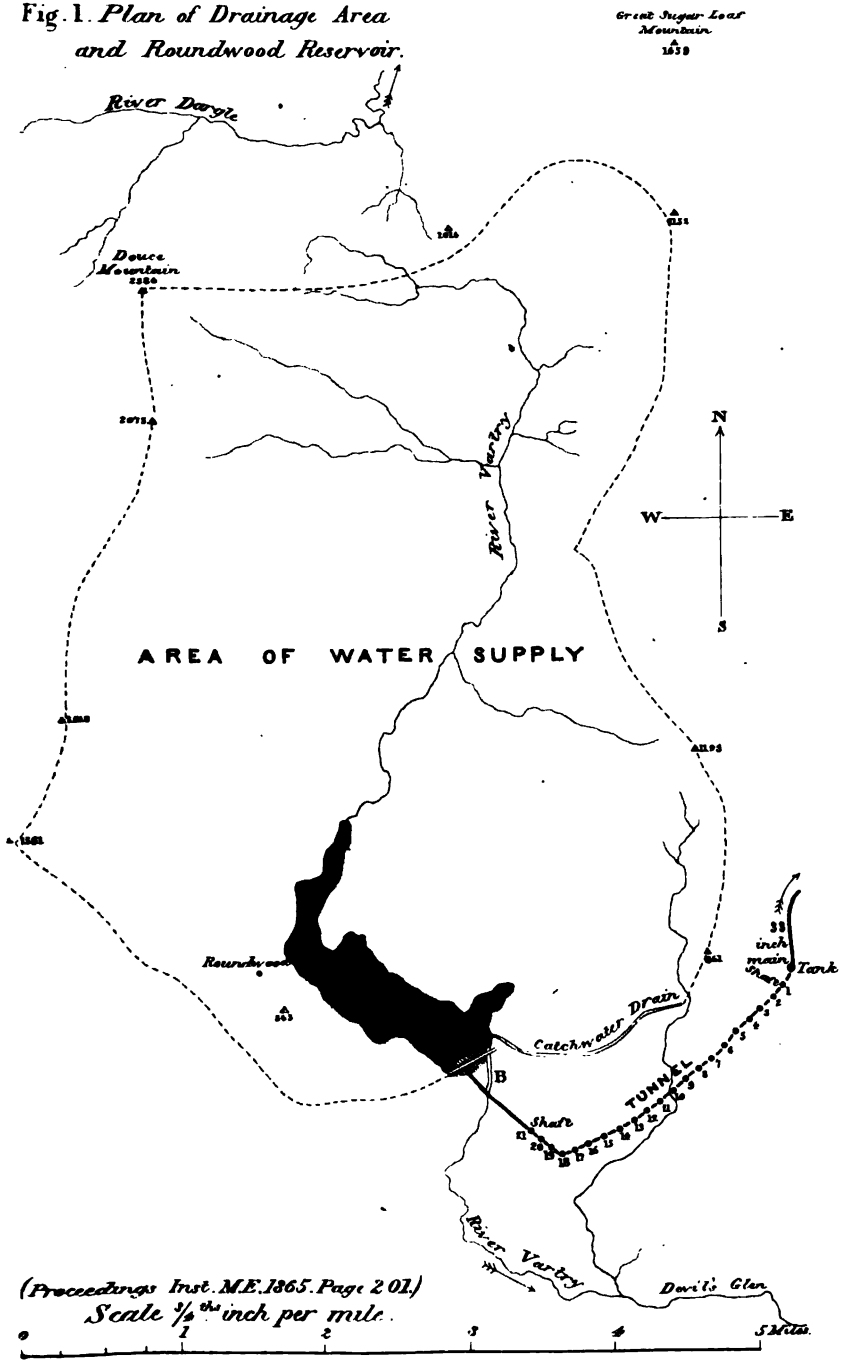
Air Compressing Engine.



Proceedings Inst. M.E. 1865. Page 179. Scale 1/16th

DUBLIN WATER WORKS. *Plate 60.*

Fig. 1. *Plan of Drainage Area and Roundwood Reservoir.*



DUBLIN WATER WORKS. *Plate 61.*

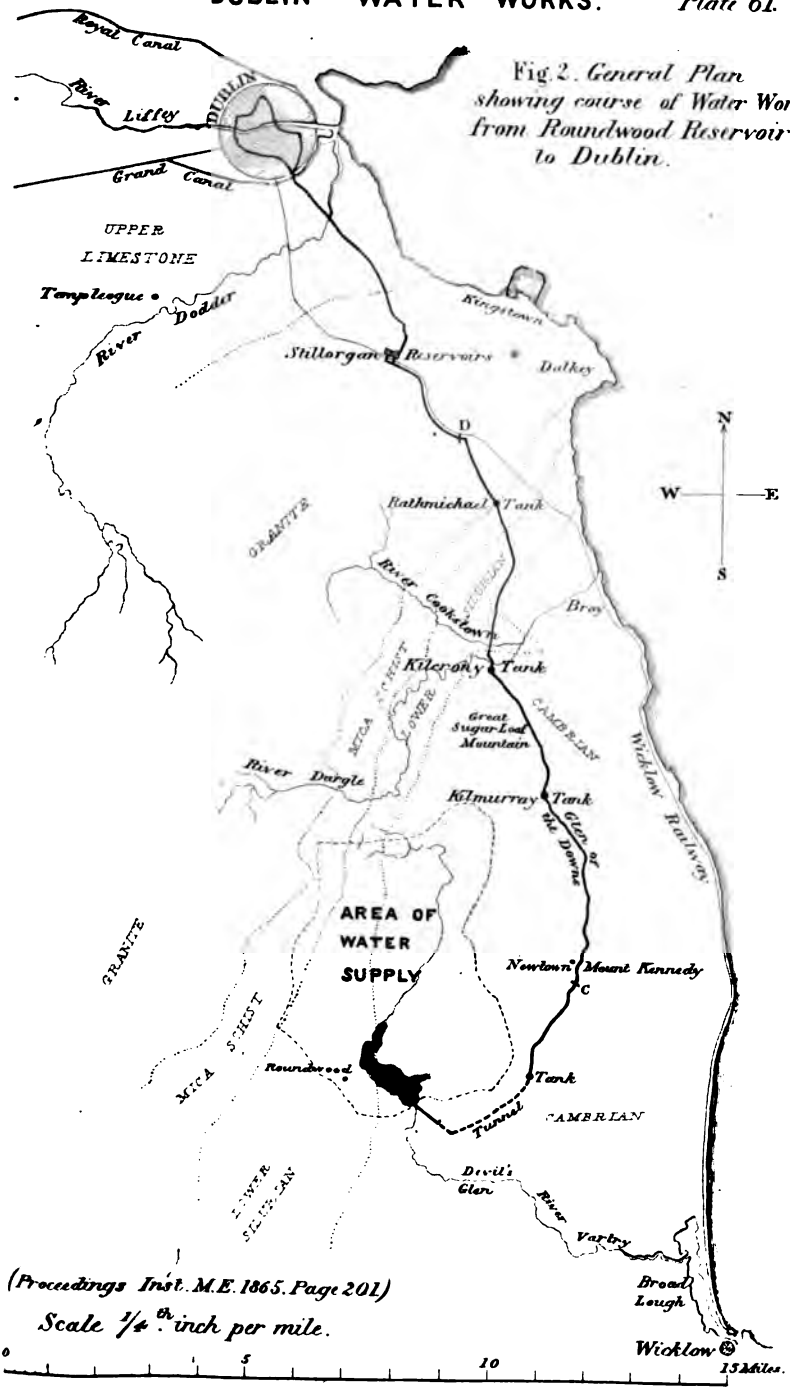
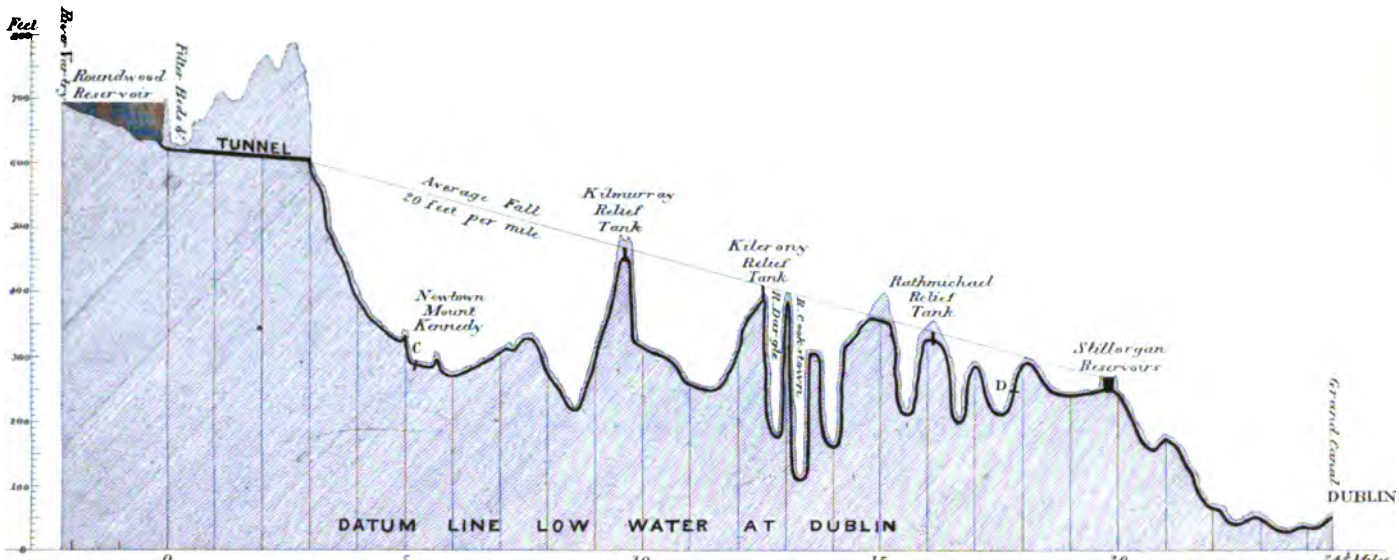


Fig. 2. *General Plan showing course of Water Works from Roundwood Reservoir to Dublin.*

(Proceedings Inst. M.E. 1865. Page 201)

Scale 1/4th inch per mile.

Fig. 3. *Longitudinal Section from Roundwood Reservoir to Dublin.*



(Proceedings Inst. M.E. 1865. Page 201.)

Horizontal Scale ¼th inch per mile.

Naylor's Safety Valve.

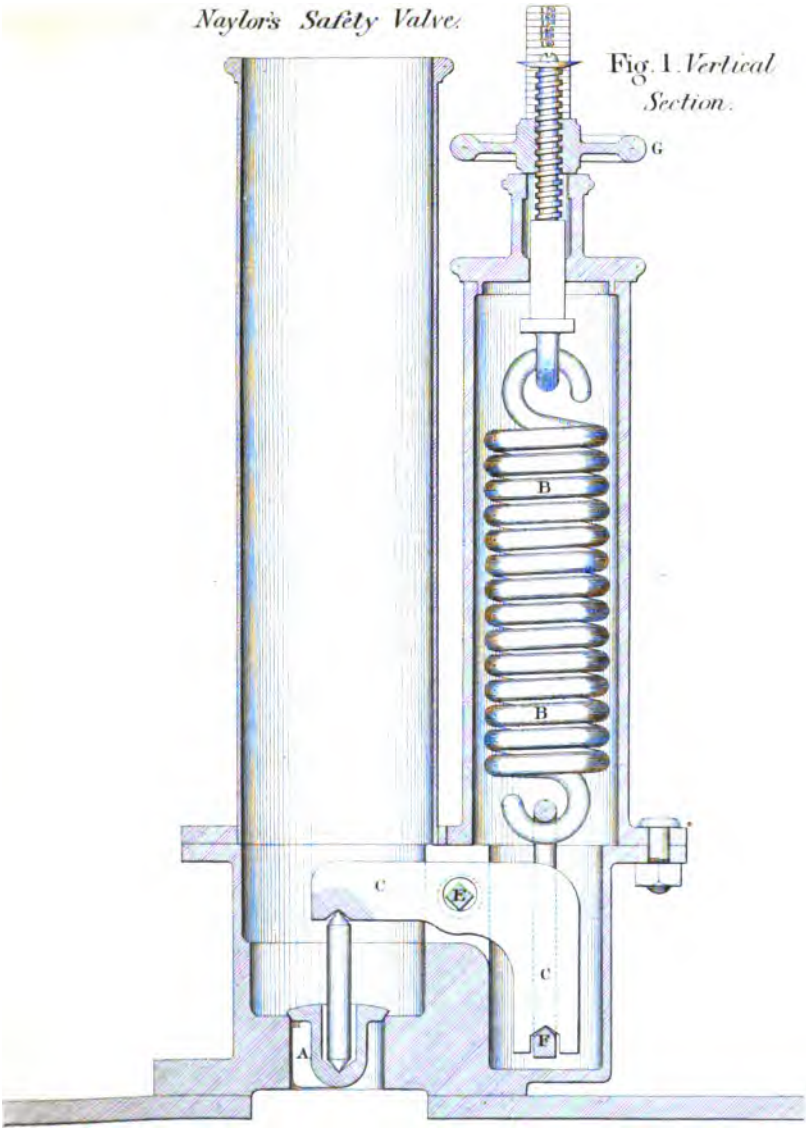


Fig. 1. *Vertical Section.*

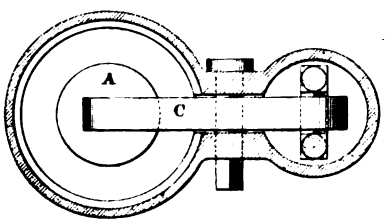


Fig. 2. *Sectional Plan.*

(Proceedings Inst. M.E. 1865. Page 220.)

Scale 1/4 th.

Fig. 3.

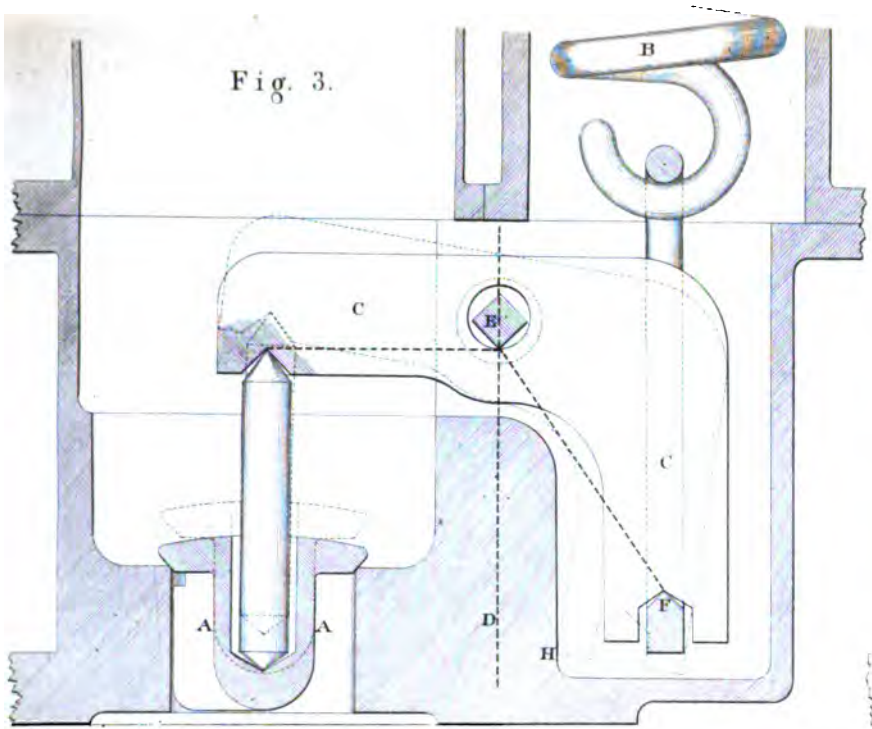
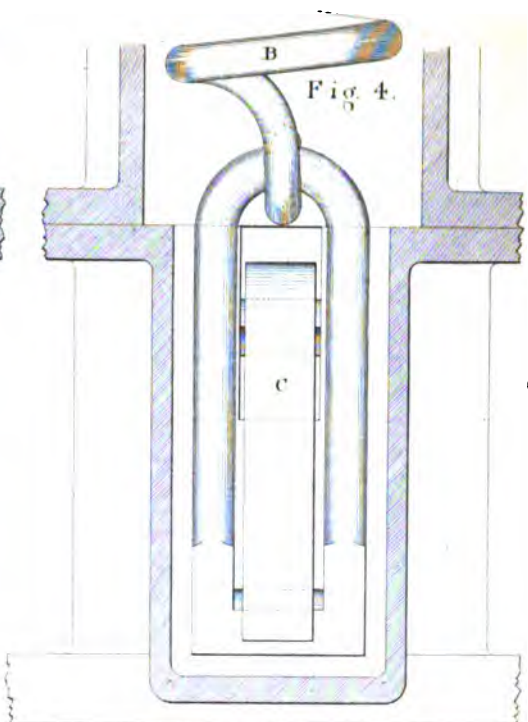


Fig. 4.



(Proceedings Inst. M.E. 1865. Page 220.)

Scale half full size.

SAFETY VALVE.

Plate 65.

Safety Valve for marine boilers.

Fig. 5.

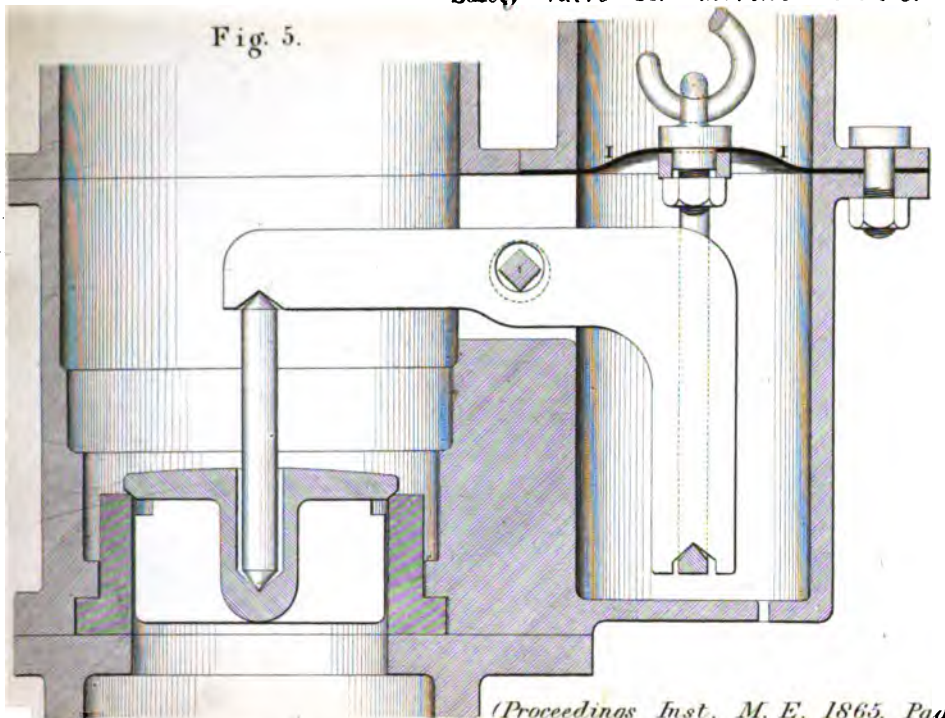
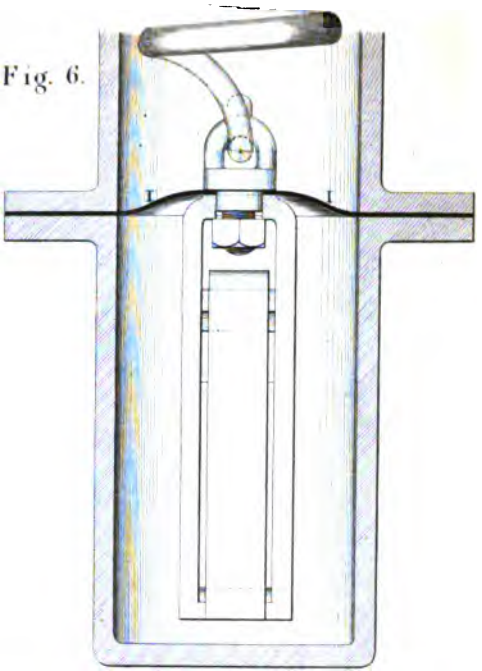


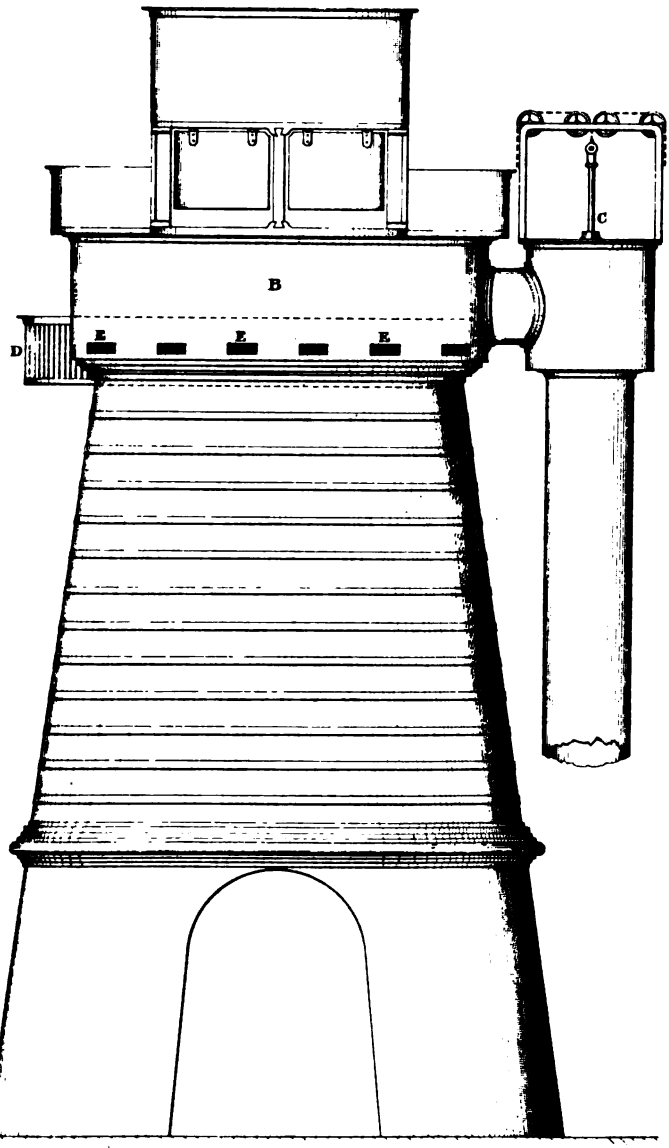
Fig. 6.



(Proceedings Inst. M. E. 1865. Page 220)

Scale 1/4 th

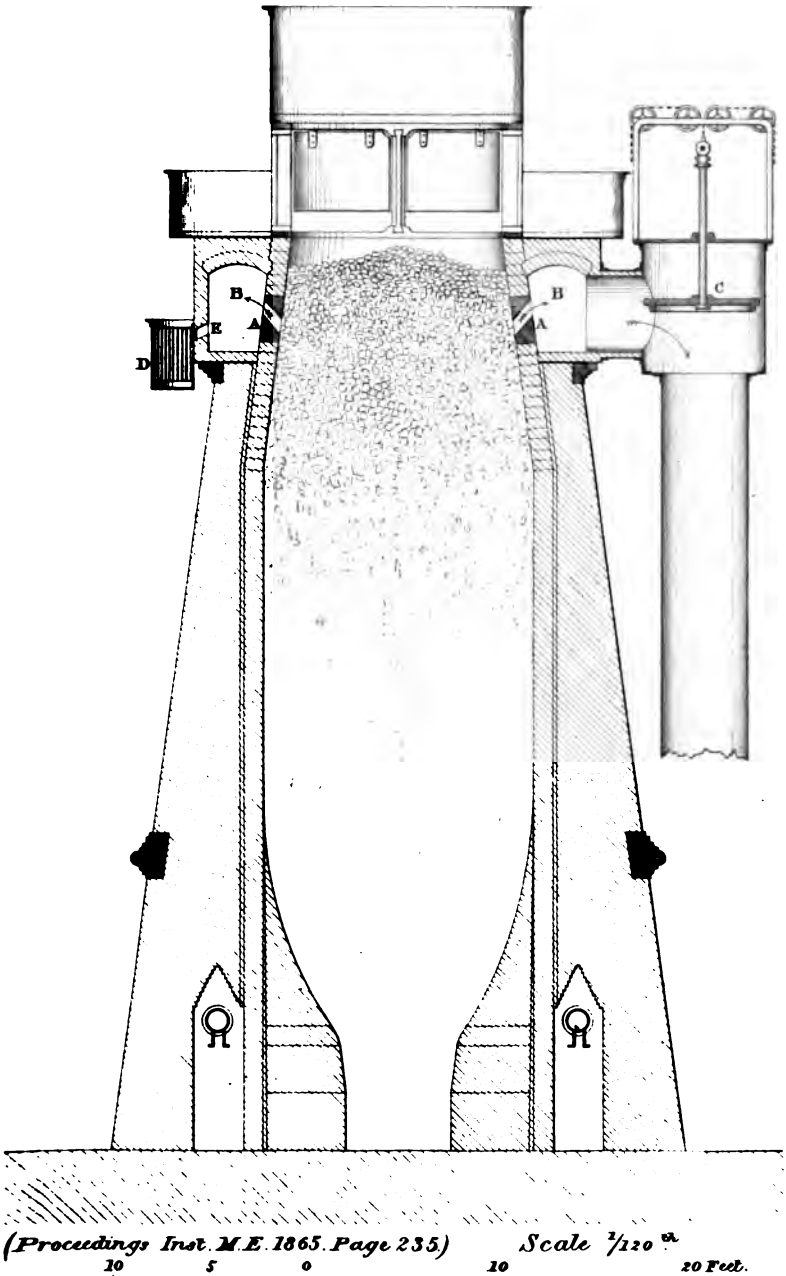
Fig. 1. *Elevation of Open-topped Blast Furnace at Rough Hay Iron Works, Darlaston.*



(Proceedings Inst. M.E. 1865. Page 235) *Scale 1/120th*

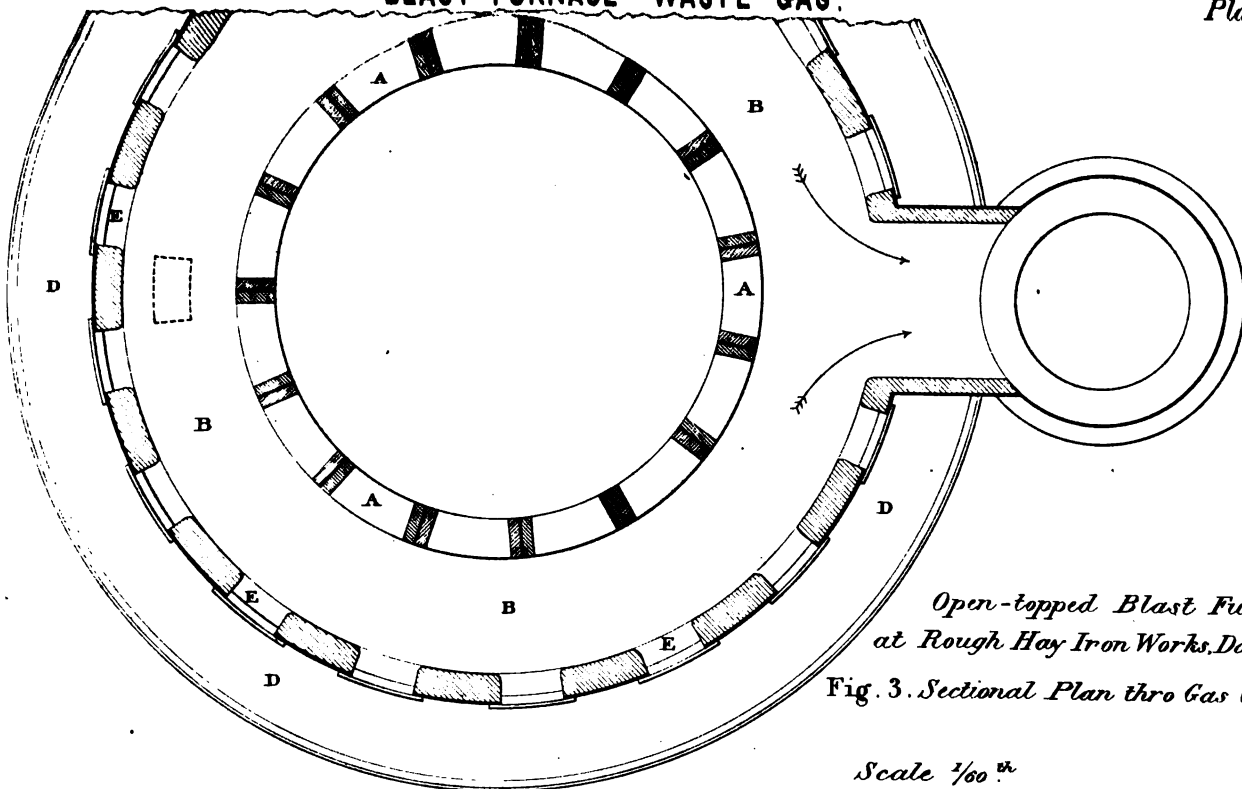
10 5 0 10 20 Feet.

Fig. 2. *Vertical Section of Open-topped Blast Furnace at Rough Hay Iron Works, Darlaston.*



BLAST-FURNACE WASTE GAS.

Plate 68.



Open-topped Blast Furnace at Rough Hay Iron Works, Darlaston.

Fig. 3. *Sectional Plan thro Gas Openings.*

Scale 1/60th

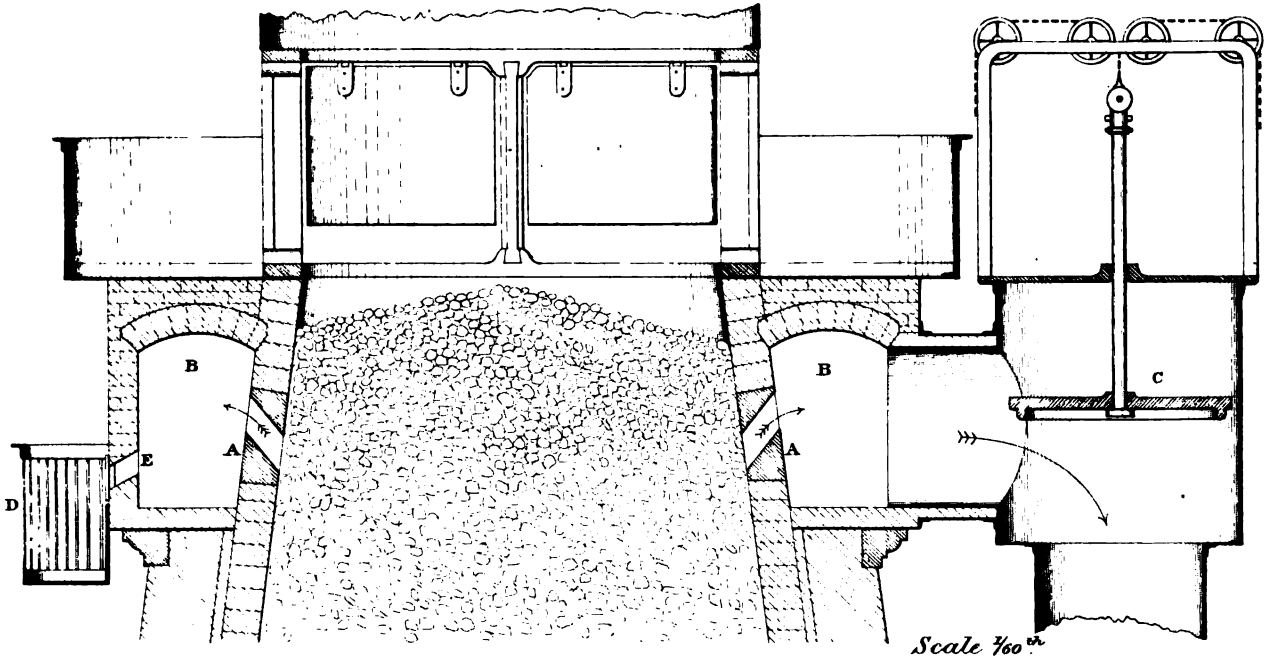
0 5 10 15 20 Feet.

(Proceedings Inst. M.E. 1865. Page 235.)

BLAST-FURNACE WASTE GAS.

Plate 69.

Fig. 4. *Enlarged Section of Open Top of Blast Furnace at Rough Hay Iron Works, Darlaston.*



(*Proceedings Inst. M. E. 1865. Page 235.*)

GUNMETAL TUYERE.

Plate 71.

Fig. 1. *Longitudinal Section of Cast Iron Tuyere.*

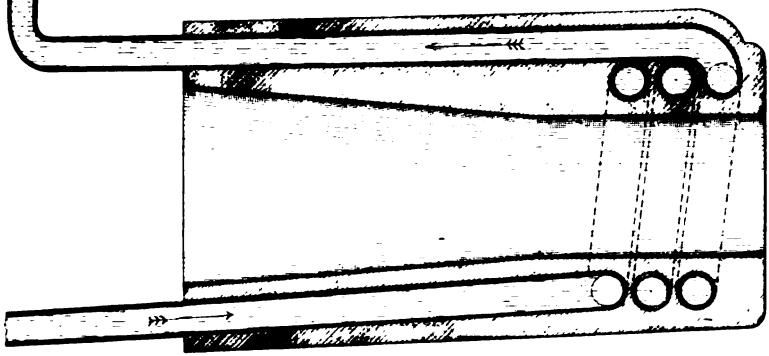


Fig. 3. *Back Elevation of Wrought Iron Tuyere.*

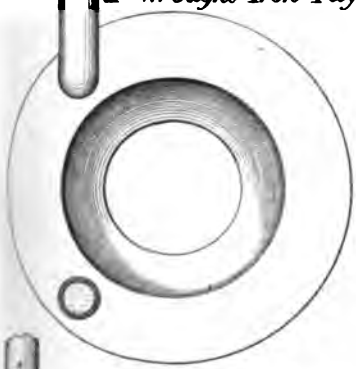
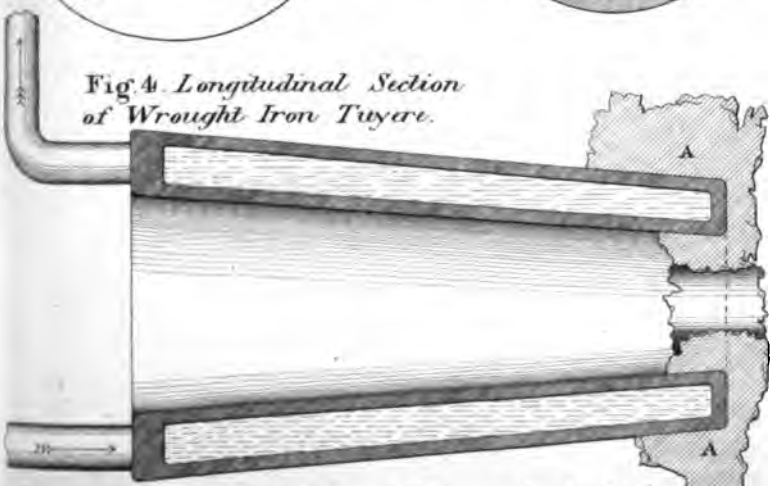


Fig. 2. *Transverse Section of Cast Iron Tuyere.*

Fig. 4. *Longitudinal Section of Wrought Iron Tuyere.*



(Proceedings Inst. M.E. 1865. Page 256)

Scale 1/6th.

0 5 10 15 20 Inches.

GUNMETAL TUYERE.

Fig.5. *Back Elevation.*

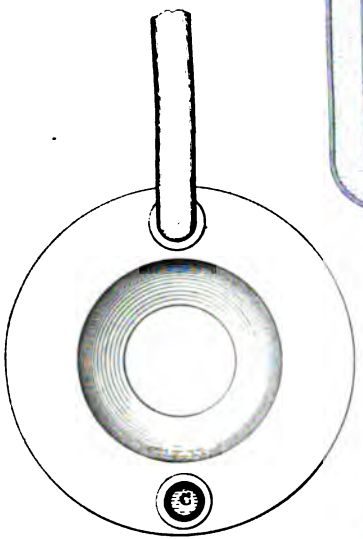
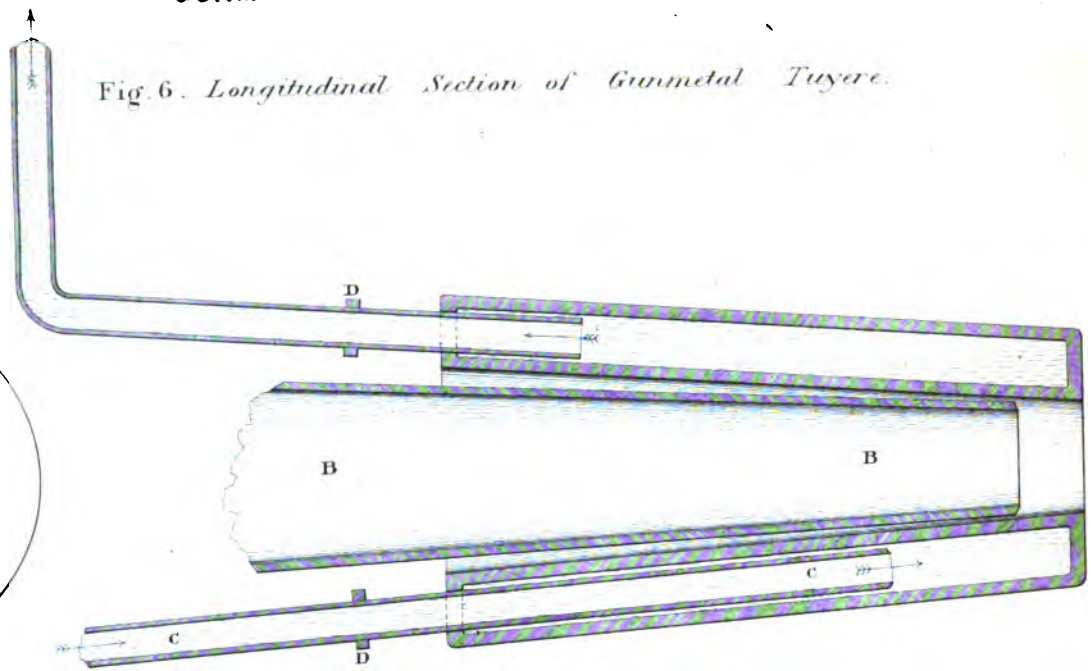


Fig.6. *Longitudinal Section of Gunmetal Tuyere.*



(Proceedings Inst. M.E. 1865. Page 256)

GUNMETAL TUYERE.

Fig. 7. *Longitudinal Section of improved Gunmetal Tuyere.*

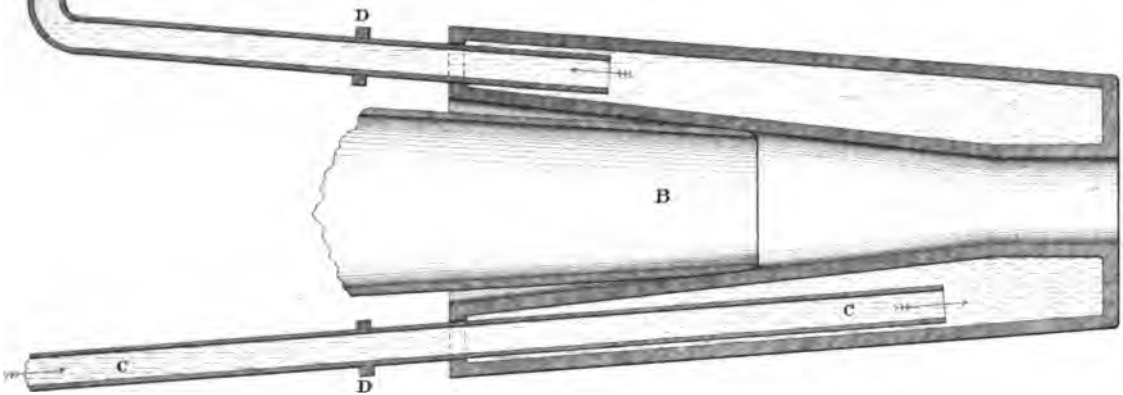
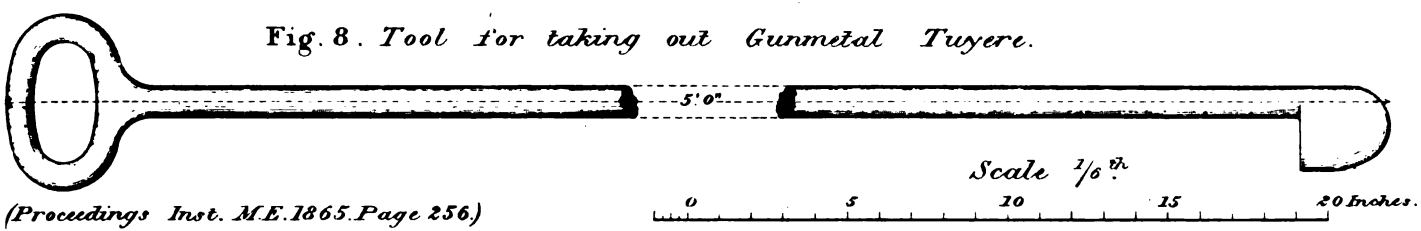


Fig. 8. *Tool for taking out Gunmetal Tuyere.*



(Proceedings Inst. M.E. 1865. Page 256.)

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1866.

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WITH YEAR OF ELECTION.

1866.

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1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1866. Adams, William, Locomotive Superintendent, North London Railway, Bow, London, E.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Bridge Street, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1865. Alleyne, John Gay Newton, Butterley Iron Works, Alfreton.
1859. Alton, George, Midland Road, Derby.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.
1856. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, Kent, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Iron Works, near Chesterfield.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. Armstrong, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1866. Baines, William, London Works, Soho, near Birmingham.
1866. Baker, Samuel, 22 Oil Street, Liverpool.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1865. Barclay, William, 4 College Lane, Liverpool.
1866. Barker, George, Messrs. Barker and Cope, Kidsgrove, Stoke-upon-Trent.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1866. Barnard, Clement, 2 Staples Inn, Holborn, London, W.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.
1865. Bass, William, Solway Screw Bolt and Rivet Works, Workington.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby.
1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1865. Bell, John, Belmont House, Timperley, near Manchester.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1865. Bennett, Henry, Wombridge Iron Works, near Wellington, Shropshire.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1865. Benson, George Henry, Stalybridge.
1865. Benson, Martin, 14 Hinde Street, Manchester Square, London, W.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1863. Birckel, John James, Regent's Canal Iron Works, Eagle Wharf Road, London, N.
1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Dudley.
1866. Bladen, Charles, Provan Mill House, Springburn, near Glasgow.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.
1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.
1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.
1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)
1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.
1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.
1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1865. Brock, Walter, Vulcan Foundry, Glasgow.
1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)
1866. Brown, Andrew Betts, Vauxhall Iron Works, London, S.
1866. Brown, Charles James, Unity Chambers, Temple Street, Birmingham.
1865. Brown, George, Rotherham Iron Works, Rotherham.
1863. Brown, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel and Iron Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of W. J. Butler, Chipping Hill, Witham).
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1866. Carpmael, William, Jun., 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1864. Carrington, William Thomas, St. Leonard's Iron Works, Perth.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1865. Cartwright, John, New Bond Street Iron Works, Birmingham.
1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris.
1857. Chrimes, Richard, Brass Works, Rotherham.
1866. Claridge, Thomas, Phœnix Foundry, near Bilston.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Knott Mill Iron Works, Manchester.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1866. Cleworth, Charles, Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, India.
1847. Clift, John Edward, Prospect Hill, Redditch.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1865. Coates, Victor, Lagan Iron Works, Belfast.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
1848. Corry, Edward, 8 New Broad Street, London, E.C.

1857. Cortazzi, Francis James, care of Hugh Hornby, Sandown, Wavertree, Liverpool.
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 3 East Parade, Sheffield.
1863. Craig, Andrew, 6 Cecil Place, Paisley Road, Glasgow.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.
1865. Curtis, Matthew, Phœnix Foundry, Chapel Street, Manchester.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1866. Daniel, Edward Freer, Abbey Iron Works, Shrewsbury.
1866. Daniel, William, St. John's Hill, Shrewsbury.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Tredegar.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1865. Davies, Benjamin, Huyton Bleach Works, near Chorley.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1864. Dewhurst, John, Lancashire Steel Works, Gorton, Manchester.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1865. Domville, Charles Kelloch, Resident Engineer and Locomotive Superintendent, Belfast and County Down Railway, Belfast.
1865. Douglas, Charles P., Consett Iron Works, near Gateshead.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.

1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1866. Downey, Alfred C., Ormesby Iron Works, Middlesbrough.
1847. Dubs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1854. Dunn, Thomas, 26 Market Street, Manchester.
1864. Dunn, Thomas Edward, Jumna Bridge, East Indian Railway, Allahabad, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1866. Elce, John, Phœnix Iron Works, Manchester.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1865. Elliot, Walter, Civil Engineer to the Colonial Government, Gibraltar.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1864. Etienne, Antonin, Engineer, Cordova and Seville Railway, Seville, Spain.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1865. Faviell, Samuel Clough, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 67 Camden Street, Parade, Birmingham.
1854. Fernie, John, Clarence Iron Works, Leeds.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1861. Field, Joshua, Cheltenham Place, Lambeth, London, S.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1861. Fleetwood, Daniel Joseph, 58 Broad Street, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1864. Foster, Edward Henry, Old Park Hall, Walsall.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 27 Cornhill, London, E.C.
1866. Fowler, George, Mining Engineer, Ashby-de-la-Zouch.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1866. Fox, Charles Douglas, 8 New Street, Spring Gardens, London, S.W.
1864. Frankish, John, 1 Lord's Chambers, Corporation Street, Manchester.
1859. Fraser, John, 18 York Place, Leeds.
1866. Fraser, John Simpson, Carriage and Wagon Superintendent, Great Western Railway, Paddington, London, W.
1856. Freeman, Joseph, 98 Cannon Street, London, E.C.
1864. Frost, Thomas, Canal Street Iron Works, Derby.
1852. Froude, William, Elmsleigh, Paignton, Torquay.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1865. Gainsford, William Dunn, Sheffield Coal Co., Sheffield.
1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1865. Gibbs, William, Deepfields Iron Works, near Wolverhampton.
1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.
1865. Gray, John McFarlane, Vauxhall Foundry, Liverpool.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 14 St. Ann's Square, Manchester.
1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.

1865. Greig, David, Steam Plough Works, Leeds.
1866. Grice, Edwin James, Stour Valley Works, Spon La
1860. Grice, Frederic Groom, Stour Valley Works, Spon
1866. Gurden, Charles Frederick, Superintendent Engi
Plate Steam Boat Co., 43 Canning Street, Birke

1863. Hackney, William, 3 Great George Street, Westmi
1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gates
1864. Halkett, John Craigie, Cramond Iron Works, Edinb
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Aus
1857. Hall, William, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co.,
Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Man
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, 1 Westminster Chamb
Westminster, S.W.
1865. Harrison, William, Bank Foundry, Blackburn.
1865. Harrison, William Arthur, Cambridge Street Works
1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering,
1858. Haswell, John A., North Eastern Railway, Loc
Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow. (*Life M*
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon S
1856. Hawksley, Thomas, 30 Great George Street, Westm
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyn
1848. Hawthorn, William, Forth Banks, Newcastle-on-Ty
1862. Haynes, Thomas John, Calpe Foundry, North Front
1860. Head, John, Messrs. Ransomes and Sims, Orwell W
1858. Head, Thomas Howard, 9 Dowgate Hill, London, E.
1853. Headly, James Ind, Eagle Foundry, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Assistant Engineer, Ceyl
Ceylon: (or care of John J. Heath, 105 Vyse Str
1864. Heathfield, Richard, Lion Galvanising Works,
Birmingham.
1860. Heaton, George, Royal Copper Mint, Icknield Street
1865. Heptinstall, John, Rotherham Iron Works, Rotherh
1865. Hetherington, John Muir, Vulcan Works, Pollard St
1866. Hetherington, Thomas Ridley, Vulcan Works, Polla

64. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
66. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
64. Hide, Thomas C., 46 Fenchurch Street, London, E.C.
63. Hind, Roger, Scotland Bank Iron Works, Warrington.
62. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
66. Hodgson, Charles, 40 Avenue du Roi de Rome, Paris.
58. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
52. Holcroft, James, Shut End, Brierley Hill.
66. Holcroft, Thomas, Bilston Foundry, Bilston.
65. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
63. Holt, Francis, Gorton Foundry, Manchester.
48. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
60. Hopkins, James Innes, Tees Side Iron Works, Middlesbrough.
66. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
56. Hopkinson, John, London Road Iron Works, Manchester.
58. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
58. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
51. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
58. Hosking, John, Gateshead Iron Works, Gateshead.
66. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
64. Howard, Elliot, 84 Upper Whitecross Street, London, E.C.
60. Howard, James, Britannia Iron Works, Bedford.
60. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
61. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
66. Hoyle, William Jennings, Messrs. Whitworth and Co., Chorlton Street, Manchester.
64. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
47. Humphrys, Edward, Deptford Pier, London, S.E.
59. Hunt, James P., Gospel Oak Iron Works, Tipton.
56. Hunt, Thomas, 23 West Cliff, Preston.
64. Hutchinson, Edward, Skerne Iron Works, Darlington.
63. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.
65. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, Camberwell, London, S.) (*Life Member.*)

57. Inshaw, John, Engine Works, Morville Street, Birmingham.
66. Ireland, William, 41 Beech Lane, Macclesfield.

65. Jackson, John, Harbour of Refuge Works, Alderney.
59. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1866. Jaeger, Herrmann Frederic, Gorton Foundry, Manchester.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.
1865. Jarvis, Edward George, Park, Gloucester.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesbrough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
1866. Kershaw, John, 24 Duke Street, Westminster, S.W.
1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1866. Knap, Conrad, 5 Bridge Street, Westminster, S.W.
1863. Knight, Thomas, 130 Bradford Street, Birmingham.

1866. Lambert, William Blake, Berwick-upon-Tweed.
1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 11 Park Grove, Bromley, Kent, S.E.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Junction Works, Miles Platting, Manchester.
1865. Leigh, Frederick Allen, Junction Works, Miles Platting, Manchester.
1866. Leigh, Joseph, Ellesmere Foundry, Patricroft, near Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1866. Little, George, Hartford Iron Works, Oldham.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Moor Hall, Sutton Coldfield, near Birmingham.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.

1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1859. Lord, Thomas Wilks, Bank Mills, Leeds.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1865. Lundh, Sverier Hakon, 9B New Broad Street, London, E.C.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Peninsular and Oriental Steam Navigation Co., Hong-Kong, China: (or care of C. Hall, P. and O. S. N. Co., Southampton.)
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Cyclops Steel and Iron Works, Sheffield.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1865. Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.
1862. Marshall, James, 4 Gloucester Terrace, Rye Hill, Newcastle-on-Tyne.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 13 High Street, Stourbridge.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.
1857. Masselin, Armand, Glass Works, Folembray, Aisne, France.
1853. Mathews, William, North Grove, Great Malvern.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)
1864. Maudslay, Thomas Henry, Cheltenham Place, Lambeth, London, S.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.

1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Engineer and Shipbuilder, Rio de Janeiro, Brazil: 11 Commerce Chambers, Lord Street, Liverpool.
1859. Maylor, William, East Indian Iron Works, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)
1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1864. McEwen, Lawrence Thompson, Ormesby Iron Works, Middlesbrough.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Worcester Engine Works, Worcester.
1862. McPherson, Hugh, Ethelbert Villa, Kingsholme, Gloucester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, 107 Lionel Street, Birmingham.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, The Grange, Surbiton Hill, Kingston-on-Thames.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Birkenhead.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1865. Morton, Robert, Brass Works, Stockton-on-Tees.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1866. Muir, Andrew, Britannia Works, Sherborne Street, Strangeways, Manchester.
1863. Muir, William, 57 Claverton Street, Pimlico, London, S.W.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1866. Newdigate, Albert Lewis, care of Charles P. B. Shelley, 21 Parliament Street, Westminster, S.W.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, care of Anthony Nichol, 19 Quay, Newcastle-on-Tyne.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1866. Oliver, William, Victoria Foundry, Chesterfield.
1861. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1866. Parton, Thomas, Rough Hay Iron Works, Darlaston, near Wednesbury.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.
1866. Peele, Arthur John, New Cross Works, Deptford, London, S.E.
1848. Penn, John, The Cedars, Lee, Kent, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.
1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.
1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Wolsingham, near Darlington.
1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.
1859. Platt, John, M.P., Hartford Iron Works, Oldham.

1862. Player, John, Norton, near Stockton-on-Tees.
1866. Plum, Thomas Edward Day, Atlas Works, Manchester.
1861. Plum, Thomas William, Ravensdale Iron Works, Tunstall, near Stoke-upon-Trent.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.
1866. Porter, Charles Talbot, Messrs. Whitworth and Co., Chorlton Street, Manchester.
1852. Porter, John Henderson, 7 St. Mildred's Court, Poultry, London, E.C.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.
1851. Potts, John Thorpe, 200 Camberwell Grove, London, S.
1865. Pratchitt, William, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 42 Villiers Street, Sunderland.
1866. Putnam, William, Darlington Forge, Darlington.

1862. Rake, Alfred Stansfield, Bank Buildings, Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1866. Ramsden, James, Abbott's Wood, Barrow-in-Furness, Lancashire.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1866. Reynolds, Frederic Cornell, 37 Great George Street, Westminster, S.W.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Tredegar.
1863. Richards, Edwin, Tredegar Iron Works, Tredegar.
1865. Richards, Job, Rabone Bridge Iron Works, Smethwick, near Birmingham.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.
1865. Richardson, John, Borough Engineer, Town Hall, Halifax.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1865. Rideal, Samuel, 18 Hopwood Avenue, Manchester.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.

1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1865. Robinson, John, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1866. Rosthorn, Joseph De, 25 Turkenstrasse, Alsergrund, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Boston.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1860. Rumble, Thomas William, 5 Westminster Chambers, Victoria Street, Westminster, S.W. (*Life Member.*)
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1863. Ryder, William, Bark Street, Bolton.

1866. Sacré, Alfred, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1857. Samuelson, Martin, Engine Works, Neptune Street, Hull.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.
1864. Sanderson, John, Locomotive Superintendent, Whitehaven Cleator and Egremont Railway, Moor Row, near Whitehaven.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of Joseph Reid 49 Arundel Square, London, N.)

1864. Seddon, John, 31 King Street, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, United States.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.
1866. Shaw, Frank, Burton Iron Works, Burton-on-Trent.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1866. Smethurst, Joseph, Messrs. Martin and Smethurst, Guide Bridge, near Ashton-under-Lyne.
1866. Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.
1866. Smith, Fereday, Bridgewater Offices, Manchester.
1854. Smith, George, Wellington Road, Dudley.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1863. Somerville, Wallace Cochrane, London Works, Birmingham.
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Hartford Iron Works, Oldham.
1859. Spencer, John Frederick, Sunderland Engine Works, South Dock, Sunderland.
1853. Spencer, Thomas, Clough Hall Iron Works, Kidsgrove, near Stoke-upon-Trent.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1866. Stephens, John Classon, Blackhall Place Iron Works, Dublin.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1864. Stokes, James Folliott, Meole Brace, Shrewsbury.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, Highland Railway, Inverness.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Soho, near Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1864. Thomas, Thomas, Llynvi Vale Iron Works, near Bridgend.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Tickle, John, Providence Engine Works, Westbromwich.
1862. Tijou, William, 27 Great George Street, Westminster, S.W.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1865. Trow, John James, Messrs. William Trow and Sons, Wednesbury.
1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.
1865. Usher, George Moon, Beverley Iron Works, Beverley.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
1865. Vickers, Albert, Don Steel Works, Sheffield.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.
1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.
1865. Walpole, Thomas, Port of Dublin Ship Yard, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Burton Iron Works, Burton-on-Trent.
1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.
1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.
1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.
1860. Weild, William, Tipping Street, Ardwick, Manchester.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly).
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.
1847. Whitworth, Joseph, Chorlton Street, Manchester.
1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)
1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, London Iron and Steel Works, East Greenwich, S.E.
1856. Wilson, Edward, Great Western Railway, Worcester.
1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.
1865. Wilson, James Edwards, Engineer, Indian Branch Railways, Cawnpore, India.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.

1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray, William, Ship Building Yard, Burton Stather, near Brigg.
1866. Wren, Henry, London Road Iron Works, Manchester.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Vauxhall Foundry, Liverpool.
1853. Wymer, Francis W., Surveyor of Steam Vessels, Mercantile Marine Office, Dublin.

1861. Yule, William, 94 Cumberland Street, South Side, Glasgow.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Museum Building, Trinity College, Dublin.
1847. Fairbairn, William, LL.D., The Polygon, Ardwick, Manchester.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1848. Branson, George, Harborne Road, Edgbaston, Birmingham.
1864. Branson, Joseph W., Harborne Road, Edgbaston, Birmingham.
1863. Brockbank, William, 37 Princess Street, Manchester.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1863. Fairbairn, John, Newcastle Chare, Newcastle-on-Tyne.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.

1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.
1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. Lawton, Benjamin C., Benwell Grange, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1864. Peyton, Abel, Oakhurst, Church Road, Edgbaston, Birmingham.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1866. Scott, John Peers, 10 Tib Lane, Cross Street, Manchester.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., 17 Gracechurch Street, London, E.C.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1865. Warden, Thomas, Lionel Street, Birmingham.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1866. White, Richard Lewis, Great Western Railway, Swindon.
1862. Whitehead, William, Don Steel Works, Sheffield.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1866. Butler, James, Atlas Works, Manchester.
1866. Butler, Thomas Snowden, Kirkstall Forge, Leeds.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1865. Hewett, Edward Edwards, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

PROCEEDINGS.

25 JANUARY, 1866.

The NINETEENTH ANNIVERSARY MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 25th January, 1866; ROBERT NAPIER, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1866.

The Council have great pleasure, on the occasion of the Nineteenth Anniversary of the Institution, in congratulating the Members upon the very satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1865 shows a balance in the Treasurer's hands of £3474 3*s*. 10*d*. after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1865, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the large increase in the number of Members that has taken place during the last year; the total number of Members of all classes for the year being 652, of whom 15 are Life Members, 36 are Honorary Members, and 3 are Graduates, being an effective increase of 80 during the year.

The following deceases of Members of the Institution have occurred during the last year 1865 :—

Henry Peet, ...	Wolverton.
William Keld Whitehead, . .	Paraguay.
Nicholas Wood, ...	Hetton.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Smithsonian Meteorological Observations from 1854 to 1859; from the Smithsonian Institution, Washington.

Annual Report of the Smithsonian Institution for 1863; from the Institution.

Statistics of the Foreign and Domestic Commerce of the United States for 1864; from the Smithsonian Institution.

The Iron Trade of Carinthia, by Joseph de Rosthorn; from the author.

Catalogue of Swedish Iron Marks; from Mr. Christer P. Sandberg.

Mauritius Inundation Papers; from Mr. James R. Mosse.

The Main Drainage of London, by Joseph W. Bazalgette; from Mr. John Grant.

On Iron Ship Building, by William Fairbairn; from the author.

Handbook of the Steam Engine, by John Bourne; from the publisher.

The Wear and Tear of Steam Boilers, by Frederick A. Paget; from the author.

The Action of Propellers, by W. J. Macquorn Rankine; from the author.

The Bevelling of Iron Frames in Shipbuilding, ditto ditto.

Rational Approximations to the Circle, ditto ditto.

The Second Law of Thermodynamics, ditto ditto.

Collection of Drawings of the Ecole Impériale des Ponts et Chaussées, Paris; from the Ecole.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the Society of Engineers; from the Society.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Journal of the Architect and Engineers' Society for the kingdom of Hannover; from the Society.

Journal of the Royal United Service Institution; from the Institution.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Report of the Midland Steam Boiler Association; from Mr. Edward B. Marten.

United States Patent Office Report; from the Commissioners.

Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

The Mechanics' Magazine; from the Editor.

The Civil Engineer and Architect's Journal; from the Editor.

The London Journal of Arts; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

Specimen of Blenkinsop Rack Rail and Chairs; from Mr. Alexander Allan.

Specimens of improved Safety Valve for Steam Boilers; from Mr. William Naylor.

Specimens of Gunmetal and Wrought Iron Tuyeres; from Mr. N. Neal Solly and Mr. Thomas Holcroft.

Bust of the President, Robert Napier, Esq.; presented by Mr. Napier.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of

executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the last year:—

On the relative advantages of the Inch and the Metre as the Standard Unit of Decimal Measure; by Mr. John Fernie, of Leeds.

On the application of Steam Power to Cultivation; by the late Mr. John Fowler, and Mr. David Greig, of Leeds.

Description of a High-Speed Compressed-Air Hammer, for Planishing, Stamping, Forging, &c.; by Mr. William D. Grimshaw, of Birmingham.

On Machinery employed in the Preparation and Spinning of Flax; by Mr. Thomas Greenwood, of Leeds.

Description of a Portable Steam Rivetter; by Mr. Andrew Wyllie, of Liverpool.

On the Manufacture of Compressed Peat Fuel; by Mr. Charles Hodgson, of Portarlington.

Description of the Bank-Note Printing Machine at the Bank of Ireland; by Mr. Thomas Grubb, of Dublin.

Description of a Rock Boring Machine; by Mr. George Low, of Dublin.

On the new Dublin Corporation Water Works for the supply of Water from the River Vartry; by Mr. Parke Neville, of Dublin.

On an improved Safety Valve for Steam Engine Boilers; by Mr. William Naylor, of London.

On an improved method of Taking Off the Waste Gas from Open-Topped Blast Furnaces; by Mr. George Addenbrooke, of Darlaston.

Description of a Gunmetal Tuyere for Blast Furnaces; by Mr. N. Neal Solly, of Willenhall.

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Dublin last summer during the time of the Dublin International Exhibition, and in expressing their special thanks to the Local Committee, the authorities of the University of Dublin, and the Honorary Local Secretaries, Dr. Downing and Mr. G. Arthur Waller, for their excellent arrangements and the very handsome reception that was given to the Members of the Institution on that occasion; and also their thanks to the railway authorities for the special arrangements granted for the excursions. The

Council refer particularly to the great advantage afforded to the Members in the admirable opportunity provided them for visiting the important works of the Dublin Corporation Water Works, the Peat Works, Copper Works, and Lead Works; and they offer their acknowledgments to the authorities of the several works for the great facilities afforded to the Members for seeing the works and the handsome reception given to them on the occasion. The Council look forwards with confidence to the important advantages arising from the continuance of these Annual Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The Council have had under consideration for some time the following modifications in the Rules respecting the qualification and titles of Members and the Meetings of the Institution &c., and now recommend them for adoption:—

That instead of the age for the admission of both Graduates and Members being the same, namely 21 years, the age for the admission of Graduates be 3 years earlier or 18 years, and that for Members be 3 years later or 24 years.

That instead of the title of Honorary Members now applied to subscribing honorary members, the title of Associates be adopted; and that the title of Honorary Members be restricted to cases of free membership specially presented by the Council.

That all communications to the Meetings are to be the property of the Institution, and to be published only by the authority of the Council.

That the four General Meetings of the Institution in each year be as follows:—three to be in Birmingham, on the fourth Thursday in the months of January, April, and October; and the fourth to be the Annual Meeting held in the summer in different localities to be arranged by the Council; the January Meeting to be the Anniversary Meeting for the annual election of officers.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—cast iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting

pumping engines—construction of pumps—plunger pumps—bucket pumps —particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—details of pit work of pumping engines at mines.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves —improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines,

construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping

ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFER DAMS AND PILING, facts relating to construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire rope rigging—comparative strength and advantage of iron and wood ships.

GUNS, cast iron, wrought iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas— ainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, shape and size—consumption of fuel—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection,

deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The Papers are to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1865.

Cr.	£	s.	d.
By Balance 31st December, 1864	2901	19	5
„ Subscriptions from 17 Members in arrear	51	0	0
„ ditto from 1 Graduate in arrear	2	0	0
„ ditto from 568 Members for 1865	1704	0	0
„ ditto from 2 Graduates for 1865	4	0	0
„ ditto from 3 Members in advance for 1866	9	0	0
„ ditto from 1 Life Member	30	0	0
„ Entrance Fees from 95 New Members	190	0	0
„ ditto from 1 New Graduate	1	0	0
„ Sale of Extra Reports	27	2	0
„ Interest from Bank	122	7	6
	£5042	8	11

Dr.	£	s.	d.	£	s.	d.
To Printing and Engraving Reports of Proceedings	688	0	6			
Less Authors' copies of papers, repaid	37	3	6	650	17	0
„ Stationery and Printing				69	5	6
„ Office Expenses and Petty Disbursements				73	8	7
„ Coals, Gas, and Water				17	10	9
„ Expenses of Meetings				54	12	11
„ Fittings and Repairs				3	0	11
„ Travelling Expenses				42	7	0
„ Parcels				4	19	5
„ Postages				78	13	6
„ Salaries				450	0	0
„ Insurance				3	10	9
„ Rent and Taxes				119	18	9
Balance 31st December, 1865				3474	3	10
				£5042	8	11

(Signed) EDWARD JONES, } Finance Committee.
WALTER MAY, }

25th January, 1866.

MEMOIRS

OF MEMBERS DECEASED IN 1865.

HENRY PEET was born at Wigan in 1813; and after serving his time under Messrs. Thompson and Cole, engineers and millwrights, at Bolton, he had charge of the engine station of the London and North Western Railway at Preston, until his appointment in 1857 as locomotive superintendent of the Lancaster and Carlisle Railway. Subsequently, on the amalgamation of this line with the London and North Western Railway in 1862, he became manager of the locomotive works at Wolverton. He was elected a Member of the Institution in 1859, and died at Wolverton after an illness of six months on 10th February 1865, in the fifty-third year of his age.

WILLIAM H. KELD WHYTEHEAD was born in London in 1825; and after serving his apprenticeship to Messrs. J. and A. Blyth of Limehouse, he was for some years the editor of the "Artizan." In 1854 he was appointed engineer-in-chief to the Government of Paraguay, and continued to occupy that post up to the time of his death. The arsenal at Assumption, the capital of Paraguay, was organised by him; and with the assistance of a staff of English workmen and English tools he executed many other important works, and kept in efficient order a considerable fleet of steam vessels. His services were highly valued by the Government of Paraguay, but his health having been for nearly three years in a weak state, the additional labour and anxiety thrown upon him, in consequence of the war between Paraguay and Brazil, proved too much for his strength, and he died at Assumption on the 13th July 1865 at the age of forty. He was elected a Member of the Institution in 1852.

NICHOLAS WOOD, of Hetton Hall in the county of Durham, was born on 24th April 1795, at Ryton, Durham; and was sent by Sir Thomas Liddell of Ravensworth to the Killingworth Colliery to learn the profession of colliery viewer. Here he became acquainted with the late George Stephenson, and was associated with him in his inventions and experiments in connection with the Safety Lamp and the Locomotive Engine; and although he continued his profession of mining engineer, he was also intimately connected with the progress of the locomotive and railways. In 1822 he entered into a discussion of the superiority of locomotives over stationary engines for working railroads; and in 1825 he published a practical treatise on railroads, giving the results of extensive and important experiments on the subject. In 1829 he was appointed one of the judges to award the premium offered by the Liverpool and Manchester Railway for the best locomotive engine. In 1845 he was engaged in the battle of the gauges, being in favour of the narrow gauge; and he was also connected with various railways as engineer and as a director. Mr. Wood occupied a leading position in his profession of mining engineer, and held many important appointments, being the mineral adviser to the Durham Bishopric Estates and to Lord Ravensworth, and also manager of the Hetton and many other collieries; and he was frequently consulted on mining matters by Government. During the latter portion of his life he confined his attention more particularly to those mining affairs in which he himself held so large an interest. He was elected a Member of this Institution in 1858, and contributed a valuable paper on the improvements and progress in the working and ventilation of coal mines in the Newcastle-on-Tyne district within the last fifty years. He died in London on 19th December 1865 at the age of seventy.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed.

The several modifications in the Rules of the Institution, recommended in the Report of the Council, were then moved by the Chairman, and were passed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were found to be duly elected for the ensuing year:—

PRESIDENT.

JOSEPH WHITWORTH, . . .	Manchester.

VICE-PRESIDENTS.

CHARLES F. BEYER, . . .	Manchester.
WILLIAM CLAY, ...	Liverpool.
ROBERT HAWTHORN, . . .	Newcastle-on-Tyne.
SAMPSON LLOYD, ...	Wednesbury.
HENRY MAUDSLAY, . . .	London.
JOHN RAMSBOTTOM, . . .	Crewe.

COUNCIL.

JOHN FERNIE, ...	Leeds.
SIR CHARLES FOX, . . .	London.
EDWARD HUMPHREYS, . . .	London.
WALTER MAY, ...	Birmingham.
JOHN ROBINSON, . . .	Manchester.

PAST-PRESIDENTS.

Ex officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, .	Newcastle-on-Tyne.
WILLIAM FAIRBAIRN, . . .	Manchester.
JAMES KENNEDY, ...	Liverpool.
ROBERT NAPIER, . . .	Glasgow.
JOHN PENN, ...	London.

COUNCIL.

Members of Council remaining in office.

JOHN ANDERSON, . . .	Woolwich.
FREDERICK J. BRAMWELL, . .	London.
CHARLES COCHRANE, . . .	Dudley.
EDWARD A. COWPER, . . .	London.
GEORGE HARRISON, . . .	Birkenhead.
EDWARD JONES, ...	Wednesbury.
W. MONTGOMERIE NEILSON, .	Glasgow.
C. WILLIAM SIEMENS, . . .	London.
CHARLES P. STEWART, . .	Manchester.
JOHN VERNON, ...	Liverpool.

TREASURER.

HENRY EDMUNDS, . . .	Birmingham.

SECRETARY.

WILLIAM P. MARSHALL, . .	Birmingham.

The following New Members were also elected:—

MEMBERS.

CHARLES JAMES BROWN, . .	Birmingham.
WILLIAM BRYHAM, ...	Wigan.
THOMAS CLARIDGE, . . .	Bilston.
EPHRAIM DEATH, ...	Leicester.
GEORGE FOWLER, . . .	Ashby-de-la-Zouch.
GEORGE GILROY, ...	Wigan.
EDWIN JAMES GRICE, . .	Westbromwich.
CHARLES FREDERICK GURDEN, .	Birkenhead.
JOHN HARDY, ...	Armagh.
THOMAS RIDLEY HETHERINGTON, .	Manchester.
JOHN SATCHELL HOPKINS, . .	Birmingham.
JOHN KERSHAW, . . .	London.
CONRAD KNAP, ...	Birmingham.

Albert Lewis Newdigate, . .	Shrewsbury.
Thomas Parton, . . .	Darlaston.
Arthur John Peele, . . .	Shrewsbury.
Frederic Cornell Reynolds, .	London.
Thomas Rose, ...	Bilston.
Joseph De Rosthorn, . .	Vienna.
Frank Shaw, ...	Burton-on-Trent.
Fereday Smith, . . .	Manchester.
Thomas Whitwell, . . .	Stockton-on-Tees.

ASSOCIATES.

William Chadwick, . . .	Leeds.
John Peers Scott, . . .	Manchester.

The following paper was then read :—

DESCRIPTION OF AN IMPROVED CHRONOMETRIC GOVERNOR FOR STEAM ENGINES, &c.

By Mr. C. WILLIAM SIEMENS, of London.

The Chronometric Governor has already formed the subject of a paper read by the author at a former meeting of this Institution (see Proceedings Inst. M. E. 1853 page 75). It consisted in its original form of a conical pendulum, freely suspended from a universal (ball and socket) joint (see Plate 17, 1853), which was maintained in motion by a force that was independent of the engine, although constantly replenished by it; and the pendulum was therefore at liberty to rotate with a uniform velocity. A differential motion between the conical pendulum and the engine to be governed was obtained by means of a mechanical arrangement, whereby, so long as the engine continued to rotate with precisely the same velocity as the pendulum, the throttle-valve would not change its position; whereas the smallest acceleration or retardation of the engine would forthwith close or open the valve to the requisite extent, for re-establishing the equilibrium between the power and the resistance, at the speed that is prescribed absolutely by the fixed speed of the pendulum. In order to obtain uniform rotation of the pendulum, it was necessary that its angle of rotation should be maintained constant, notwithstanding the variations in the amount of its driving power that resulted from the resistance of the throttle-valve, which had to be overcome by the inertia of the pendulum at each time that a re-adjustment between the power and the load of the engine was required. This was effected by increasing on the one hand the maintaining power of the pendulum beyond what was requisite under ordinary circumstances, in order to guard against an occasional deficiency of power; and by calling into existence on the other hand an extraneous resistance by a friction break, whenever the pendulum reached its full angle of rotation, in order to prevent its further acceleration.

A considerable number of steam-engine governors were constructed by the writer in accordance with this description in the years 1844-47, which continue to work in a highly satisfactory manner up to the present day, in all cases where sufficient attention has been bestowed upon them. They continue also to be used by the Astronomer Royal for regulating the motion of telescopes and chronographical apparatus with almost mathematical precision. Notwithstanding these results however, the chronometric governor has not received an extended application, owing to its comparative costliness and the delicacy of its working parts, which require frequent attention to keep them in perfect order. The writer's early attempts to reduce this governor into a form more suited for common use were not attended with success, inasmuch as the accuracy of the instrument was found to be sacrificed in a great measure; and the endeavours of others in the same direction do not seem to have proved more satisfactory. But last year an idea occurred to the writer, which appeared calculated to furnish uniform rotation under varying circumstances of driving power, without having recourse to so delicate an instrument as the free conical pendulum; and this idea has given rise to the governor which forms the subject of the present paper.

If an open cylindrical vessel, such as a glass tumbler or cup, containing a certain quantity of water, is made to rotate upon its vertical axis, as shown in the diagram, Fig. 2, Plate 1, the water will be observed to rise round the sides of the vessel as the speed of rotation gradually increases, until it ultimately begins to overflow. If the speed be maintained uniformly from this moment, it is evident that the water will continue to reach up to the very edge of the cup; and that if the speed were then reduced and afterwards again increased to the same limit, the water edge after having fallen would again rise to the same point. The surface of the liquid in rotation takes the form of an inverted paraboloid; and the elevation to which the liquid rises, before it reaches the overflow, increases in the ratio of the square of the velocity, the elevation being measured from the apex of the inverted paraboloid to the upper edge. Thus a double velocity causes the liquid to rise to four times the height;

whence it follows that, when the speed is already sufficient to raise the liquid to the edge of the cup, a small increase of speed will produce a very decided overflow of liquid. The quantity of liquid within the cup being limited, a rise at the circumference is accompanied by a depression of the centre; and this has been taken advantage of by Mr. Ramsbottom to devise a measure of rotary velocity, (see Proceedings Inst. M. E. 1861 page 49).

The present object is not to measure velocity, but to maintain a constant predetermined velocity in steam engines and other more delicate mechanism; and for this purpose the principles of liquid gyration above referred to have been taken advantage of by the writer in the following manner.

The improved Chronometric or Gyrometric Governor for Steam Engines is shown in Figs. 3 to 7, Plates 1 to 4. It consists of an open cup A of parabolic shape, Figs. 4 and 5, fixed upon a vertical spindle B, and caused to revolve within the closed chamber C containing the liquid, the bottom of the cup being open and always immersed below the surface of the liquid. When the cup is made to revolve rapidly, the liquid contained in it rises round the sides of the cup and sinks in the centre, the surface of the liquid assuming the inverted parabolic form shown in Fig. 5; and on reaching the edge of the cup it overflows into the surrounding chamber, while at the same time a fresh supply of liquid is drawn into the cup through the opening in the bottom: and the power absorbed in putting the overflowing liquid into motion offers a continuous resistance to the rotation of the cup. On a level with the edge of the cup, a series of twelve to sixteen fixed vanes D are placed round the circumference of the external chamber C, and a corresponding set of blades E are also fixed round the outside of the cup just below the rim; so that the sheet of liquid overflowing from the edge of the revolving cup is thrown against the vanes D, and by these is thrown back against the blades E on the cup, whereby the overflowing liquid is made to offer an additional resistance to the rotation of the cup. A second series of vanes and blades can also be added below if desired, for still further increasing the resistance, and thereby increasing the

power of the revolving cup as a governor of speed. The internal radial arms uniting the shell of the cup A to the centre boss, as shown in Fig. 6, serve to communicate the rotary motion to the liquid inside the cup; while the bottom of the external chamber C is provided with a number of radial ribs, as shown in Fig. 5, for the purpose of checking rotary motion in the liquid outside the cup.

So long as the cup is driven at a constant speed, the overflow is constant, and produces an absolutely constant resistance; and hence, if the cup be driven by a constant driving power, independent of the engine, its speed is as uniform as that of a chronometer, within a very small margin of variation which is definitely fixed; and it continues revolving at an unchanging speed, totally independent of the engine, and consequently affords the means of forming a governor for controlling the speed of the engine to a constantly uniform rate. The constant power for driving the cup is obtained by the weight F, Fig. 4, on the lever of the throttle-valve spindle G, which is connected with the spindle of the cup A and also with the main driving shaft H of the engine, through a set of differential wheels and a rocking frame turning loose upon the spindle of the cup. The main driving shaft H of the engine drives the vertical shaft K, which carries the inverted wheel L; and on the bottom of the spindle B of the regulating cup, which is in a line with the shaft K, is fixed the pinion J, the diameter of which is one quarter that of the wheel L. Both wheel and pinion gear into the two intermediate wheels I I, as shown in the inverted plan, Fig. 7; these run loose upon studs, and are suspended from the rocking frame M, which is free to rock upon its centre, but is connected with the throttle-valve G by the connecting rod N and bell-crank lever. The weight F therefore upon the horizontal arm of the lever produces a constant pressure against the teeth of the wheel L and pinion J; and the pinion J, in yielding to this pressure, causes the cup A to revolve, whilst the wheel L is driven by the engine in the contrary direction, tending to raise the weight. Thus the weight is constantly tending to fall, and thereby drives the governor through the differential wheels; but the action of the

engine is in the opposite direction, and is constantly tending to raise or wind up the weight.

The result therefore is that, when the engine is running at exactly the same speed as the governor, so that the wheel L makes exactly one revolution during the time that the governor allows the pinion J to make four revolutions, the rocking frame M remains stationary, holding the throttle-valve constantly in one position, and the weight F neither rises nor falls. But whenever the speed of the engine exceeds or falls short of the proper rate, by even the slightest variation, the differential action of the wheels is instantly called into play, and causes the rocking frame to be shifted in position in the direction of the relatively faster wheel, and thereby closes or opens the throttle-valve to a sufficient extent to bring back the engine at once to the proper rate fixed by the governor. The engine is therefore compelled to run with the same regularity of speed as the governor, while the regularity of the governor is ensured by the driving power being derived from the constant weight, which will always remain in free suspension; because before reaching its lower stop in falling, the whole of the steam would be turned on and would accelerate the engine to raise it; and before reaching its upper stop in rising, the supply of steam would be so much reduced as to retard the engine, even if all its work were thrown off, and give the preponderance of power to the weight.

The important difference in principle of action between the new chronometric governor and the ordinary steam-engine governors at present in general use lies in the fact that the ordinary governors regulate the speed to a uniform standard rate only under the special conditions of work for which they are adjusted, and whenever those conditions are altered the standard of speed becomes altered also. Thus an engine having the full amount of work put upon it, and governed by an ordinary ball governor, will be kept to a uniform speed by the governor so long as the average resistance to be overcome by the engine continues the same; but whenever any of the work is taken off, the speed of the engine will

be increased to a higher rate corresponding to the diminished resistance, and at this higher rate the speed will then be kept uniform by the governor so long as the diminished resistance continues without further alteration. This arises from the circumstance that the degree of opening of the throttle-valve is directly controlled by the angle to which the governor balls are raised by the velocity of their revolution, the throttle-valve being moved only by a change in the angle of suspension of these balls; whence it follows that a larger supply of steam for overcoming any increase of work can be obtained only in conjunction with a smaller angle of the governor balls, and consequently with a lower speed; and that a larger angle of the governor balls and consequently a higher speed must be attained, in order to reduce the supply of steam for meeting any reduction in the work done by the engine. In the chronometric governor on the contrary, it will be seen that the governor is not driven by the engine itself, as is the case in the ordinary ball governors, but by the constant weight on the throttle-valve lever, whereby a constant speed of the governor is ensured; and the slightest deviation of the engine from this fixed speed causes the throttle-valve to be either opened or closed to the extent requisite for bringing back the engine to that same rate. Thus the degree of opening of the throttle-valve and the consequent supply of steam to the engine are altogether independent of the speed of either the engine or the governor; and the quantity of steam supplied to the engine is always exactly equivalent to the quantity of work to be performed, while the speed of the engine is maintained unchangeably the same, to whatever extent the work upon it may be diminished or increased within the limit of work which the engine is capable of doing with its full supply of steam.

It will be shown in the subsequent portion of the present paper that, when water is the liquid employed in the governor, a cup of 6 inches diameter and 6 inches height of rim above the water level, without external blades, is capable of absorbing 0·004 horse power without suffering an increase of speed exceeding 2 per cent.; but it is shown by experiment that the addition of the external blades E round the cup and the set of fixed vanes D in the external chamber,

Figs. 5 and 6, increases the power of the cup to 0·007 horse power, without any greater increase of speed. Assuming that the work required to be performed by such a governor consists in moving a throttle-valve through a range of 6 inches (0·5 foot) in 5 seconds (0·083 minute), then the power of the governor is sufficient to overcome a resistance at the throttle-valve of

$$\frac{0{\cdot}007 \times 0{\cdot}083 \times 33000}{0{\cdot}5} = 38{\cdot}35 \text{ lbs.}$$

and it is evident that a resistance of 38 lbs. far exceeds what may reasonably be expected of a regulating valve. It must be observed that the increase of speed due to the development of this amount of force ceases as soon as the work is accomplished, or in a few seconds of time; after which the cup and with it the engine will resume the normal rate. The governor shown in Figs. 5 and 6 has a cup 8 inches diameter, which would be capable of overcoming a still greater resistance.

If it is desired, instead of moving a simple throttle-valve, that the governor should act upon a variable expansion valve, or even upon the sluice of a waterwheel, requiring considerable power to move it, the rocking frame may be arranged as a pulley or wheel, and may be connected to the work in such a manner that several of its own revolutions are required to accomplish the necessary action, thereby gaining power at the expense of time.

The liquid that is employed in this governor is either water or paraffin oil; and the chamber C, Fig. 5, containing the liquid and revolving cup, is virtually closed, so that no loss from evaporation takes place. The absolute speed of the governor is determined by simply changing the total quantity of liquid in the chamber C, the level being shown by the gauge glass O at the side of the chamber, Fig. 3, which is graduated for the different speeds. The liquid is filled in when required through the closed hole P in the cover of the chamber, which serves also for supplying oil occasionally into the lubricating cup upon the top of the spindle B.

One of these governors, working with water, and having a cup of 6 inches diameter and 6 inches height, has now been in constant operation for several months at the writer's telegraph works at Woolwich, employed in regulating a high-pressure engine running

at high speed with very variable load, over which the ordinary ball governor previously used had so little control that the engineman was obliged to regulate the speed continually by the hand stop-valve. The new governor maintains the engine at an exceedingly uniform speed, under the most extreme variations of load; and no trouble of any kind has been experienced in its working.

In the new governor it will be observed that all the parts are readily accessible. The two vertical spindles B and K, Fig. 5, rotate in complete balance, and are therefore not liable to wear sideways. This governor is also equally applicable on board ship, as a vertical position of the revolving cup of liquid is by no means necessary. These are decided advantages in favour of the new governor over the former chronometric governor, the principle of this governor having already been approved by many mechanical engineers.

The principle of the revolving cup of liquid has also been applied in a more delicate and an absolutely chronometric form, as shown in Fig. 1, Plate 1, for regulating clockwork and telegraph apparatus, where the variations of speed to which the machinery is exposed are not by any means either so sudden or so large in amount as in the case of a steam engine. The cup A is mounted upon a spindle B driven direct by the clockwork or apparatus that is required to be governed chronometrically; but instead of being fixed on the spindle, the boss of the cup runs free upon a quick double-threaded screw formed on the spindle, and the driving power to make the cup revolve with the spindle is conveyed through a spiral spring S, attached to the spindle and cup, which also supports the weight of the cup and liquid when running at the normal speed and with the proper amount of overflow. The result of this arrangement is that the depth of immersion of the cup in the liquid is self-adjusting; whereby any tendency to change of speed, arising from the slightest change of driving power, is instantly compensated by a corresponding change in the resistance to rotation, while the absolute speed of the cup continues constant without any alteration.

The chronometric correctness of the governor in this more delicate and perfect form will be understood from the following consideration of the principles of its action.

The velocity due to the height of the rim of the revolving cup above the level of the liquid in the external chamber is $\sqrt{2gh}$, where h is the height in feet, and g is the acceleration (32 feet) produced by gravity after one second. In order therefore that the liquid may be raised so as to overflow from the rim of the cup, it must have this velocity communicated to it. The actual velocity of the overflowing liquid is the same as the tangential velocity of the rim of the cup, or $n \times c$, where n is the number of revolutions of the cup per second, and c is the circumference of the rim of the cup in feet. Hence the relation obtained for determining the speed at which a cup of given dimensions must rotate at the moment of overflow is

$$n\,c = \sqrt{2gh} \text{ or } n = \tfrac{1}{c}\sqrt{2gh}.$$

It will be observed that the specific gravity of the liquid employed does not appear at all in this formula; for the only forces acting upon the liquid in the cup are gravity, which is constant, and the centrifugal force, which results solely from the velocity of rotation of the cup, and is therefore the same for all liquids, independent of their density. Hence the density of the liquid is immaterial as regards the velocity of the cup, and affects only the driving power required to maintain the cup at that velocity.

Applying the above formula to a cup of 6 ins. diameter or 1·57 ft. circumference, the height of rim above the level of the liquid being 6 ins. or 0·5 ft., the expression becomes $n = \frac{1}{1\cdot57} \times \sqrt{2 \times 32 \times 0\cdot5}$ $= 3\cdot6$ revolutions per second; or 216 revolutions per minute must be the speed of the cup in order to maintain the liquid up to the point of overflow. The same formula also serves to determine either the diameter or the height of cup that is required to produce a given speed of revolution.

The above calculation extends at present only to the moment when overflow would commence, showing the speed at which the given cup must revolve for maintaining the liquid up to the point of overflow. The increase of speed necessary for producing an

actual overflow, and the quantity of driving power absorbed by the overflowing liquid, upon the mutual relation of which depends the practical efficiency of the governor as a chronometric regulator of speed, are readily ascertained in the following manner for any given amount of overflow.

Taking the same cup of 6 inches diameter, and assuming that the amount of overflow is 60 cubic inches per second, and that the liquid employed is water, then, the area of inlet at the open bottom of the cup being 5 square inches, the water must rush into the bottom of the cup with a velocity of 1 foot per second. In order to obtain this rapidity of flow into the cup, the apex of the liquid paraboloid or the lowest water level inside the cup must be depressed below the water level in the external chamber to the extent of the height due to a velocity of 1 foot per second ($h = \frac{1}{64} v^2$) or $\frac{1}{64} \times 1^2 = \frac{1}{64}$ foot $= 0{\cdot}19$ inch. Moreover the circumference of the 6 inch cup being 1·57 feet while its speed is 3·6 revolutions per second, the velocity of the overflowing sheet of water is $1{\cdot}57 \times 3{\cdot}6 = 5{\cdot}65$ feet per second; and therefore a height of 0·05 inch is required above the rim of the cup, in order to provide the necessary area for the overflow of 60 cubic inches per second. Hence the result of the overflow is that the effective height of the cup is increased altogether from 6 inches to 6·24 inches; and therefore the previous velocity of the cup, 216 revolutions per minute, must now be increased in the proportion of $\sqrt{6{\cdot}24}$ to $\sqrt{6}$, so that the new velocity will be 220 revolutions per minute, being an increase of 2 per cent. in the velocity for the given overflow.

The power absorbed by the overflow is that required to raise the 60 cubic inches of water per second to the height of the rim of the cup, and at the same time impart to it the velocity of overflow of 5·65 feet per second. This velocity corresponds to a height of 5·98 inches, which added to the 6·24 inches height of lift in the cup makes a total height of 12·22 inches, or say 1 foot height. The weight to be acted upon is 60 cubic inches of water or 2·17 lbs. per second, equivalent to 130 lbs. per minute. Hence the horse power absorbed by the overflow will be $130 \times 1 \div 33000 = 0{\cdot}004$ or 1-250th horse power.

Although an increase in velocity of only 2 per cent., for producing the overflow requisite to absorb so considerable an amount of surplus driving power as 1-250th horse power, may not appear of much importance in the ordinary purposes for which governors are employed, considering that this irregularity applies only to the short interval of a few seconds and is moreover reduced in amount by the addition of external blades round the cup as before described, yet it is evident that in order to obtain exceedingly uniform rotation with variable driving-power something more than the simple cup is still required. It accordingly occurred to the writer that, if by some automatic arrangement the cup could be depressed into the liquid in the precise measure of the increase of resistance caused by the overflow, then the height to which the liquid would have to be raised would remain actually the same as it was before, and the time of rotation of the cup would therefore remain the same also.

This adjustment is accordingly effected in the delicate chronometric governor shown in Fig. 1 by the introduction of the spiral spring S for connecting the cup A to the driving spindle B, the upper end of the spring being fastened to the spindle and the lower end to the centre boss of the cup, while this boss fits upon a quick double-threaded screw on the driving spindle. The vertical tension of the spring supports the weight of the cup itself and of the liquid contained in it when at the point of overflow; but it is without any torsional tension until the moment that the liquid begins to overflow. The increase of driving power which produces the overflow produces also a corresponding torsion of the spring, and consequently a corresponding depression of the cup upon the screw threads, the direction of the rotation being arranged to suit the screw; and if the torsion of the spring be so adjusted that the requisite amount of depression of the cup is effected for a given limit in the increase of driving power, then the depression for any intermediate increase will also be just sufficient to correct the error of speed, and absolutely uniform rotation between those limits of driving power will be the result.

In order to test the accuracy of these views the writer has constructed the electric clock now exhibited, in which the cup of uniform rotation takes the place of the ordinary pendulum. The driving power is derived from a small "Marie Davy" or "Daniell" battery contained within the pedestal, which requires no further attention beyond being refilled with protosulphate of mercury at long intervals. The vertical driving spindle which carries the governor cup receives motion from an electro-magnet contained within the clock, where are also reducing wheels for communicating the motion from the spindle to the hands upon the dial, and a contact arrangement whereby the electric current is alternately broken and re-established in the coil in order to obtain the rotary motion. The bottom end of the driving spindle rests on an adjustable screw, as shown at T in Fig. 1, by which the regulating cup may be raised or lowered during its action, in order to effect the adjustment of the clock, which could not be accomplished to so great a nicety or with such facility by any adjustment of the strength of the spiral spring S that supports the cup. The liquid employed in this instance is paraffin oil, which is particularly applicable for the purpose on account of its high fluidity and its neutrality in a chemical point of view.

A peculiar feature of this clock, as with the steam-engine governor already described, is that it may be tipped on one side very considerably without producing any visible change in the uniform sheet of overflowing liquid from the cup or in the velocity of revolution; and the clock may therefore be used even on board ship, where a pendulum is of course inadmissible. The writer has also applied the cup of uniform rotation to the regulating of the clockwork employed in telegraph recording instruments; and is about to use it for obtaining synchronous motion at different telegraph stations in the construction of chemical telegraphs, for which purpose he expects it will be of special value on account of removing the difficulty formerly experienced in obtaining uniform rapid rotation.

The cup of absolutely uniform rotation, with self-adjusting dip, as now described and shown in the electric clock exhibited, was the first form in which the writer embodied the idea of a revolving cup of liquid as a governor of speed. In applying this governor to a steam engine, it is evident that, if the power and the load upon the engine varied only between narrow limits, it might be possible to construct a cup of uniform rotation large enough to absorb directly all surplus power whenever it occurred, exactly the same as in the clock and other delicate machinery. But considering the actual extent of the variations in the case of a steam engine, and the importance of not sacrificing engine power, as would be the case if all surplus power were absorbed by the governor, it was necessary to seek for some means of giving the governor indirect command over the engine; and this is therefore accomplished by the use of the differential motion, and the rocking frame connected to the throttle-valve or expansion valve. At the same time the self-adjusting dip of the cup is dispensed with, the cup being no longer carried upon the driving shaft, but on a separate spindle driven independently by the constant weight; and the cup itself is made heavy, in order to increase its stability of rotation and to obtain in it a store of accumulated force, ready at any moment to act upon the throttle-valve of the engine. It has also been seen that the addition of the external blades round the rim of the cup nearly doubles its power as a governor.

The writer's practical career having commenced twenty-three years ago with the subject of the chronometric governor, although his attention has since been engrossed with other subjects, he trusts that this application of a new principle of action may lead to a more complete realisation of the object in view, namely the attainment of really uniform rotation in mechanism.

Mr. SIEMENS exhibited the regulating cup and differential wheels which had been at work in the governor employed to regulate the engine at his works at Woolwich; he also showed in work an electric clock regulated by the more delicate modification of the governor designed for that purpose.

The CHAIRMAN enquired whether in the application of the governor to marine engines the pitching of the vessel would in any way interfere with the action of the governor, as the cup containing the liquid would then be canted out of its upright position.

Mr. SIEMENS replied that the tilting of the governor into an inclined position did not interfere with its action, as was shown by tilting the clock now exhibited, when it was seen that the speed of the governor continued as regular as when it was standing upright and steady. This was in consequence of the revolving cup being made to dip into the liquid in the centre of the external chamber; so that however the governor might be tilted about, within all ordinary limits that could be met with in practice, the bottom of the cup would still remain submerged in the liquid, as the centre of the liquid would be exposed to comparatively little alteration in level. The utmost that could happen would be that the open bottom of the cup would become uncovered for an instant; but that would have no perceptible effect on the governor, as it would immediately afterwards be covered again, and the liquid would again rise up inside the cup by the centrifugal force. The rotation of the governor was produced independent of the liquid, by the action of the constant driving weight on the throttle-valve lever, and the liquid only tended to retard the speed of rotation; and even during the momentary uncovering of the open bottom of the cup, the liquid already contained in it would be supported by the centrifugal force.

The electric clock now exhibited to the meeting had been constructed specially for the purpose of testing the principle and action of the new governor, by carrying it to the extreme limits of delicacy and sensitiveness, and also in order to ascertain any small defects which might be brought to light in the working. The result had been found to be that the speed of the clock was remarkably uniform and exact, and therefore there was no doubt that this

modified form of the governor would be very useful for many purposes; for although with a steam-engine governor it was not necessary to attain anything like the regularity of a clock, yet there were many other applications of the governor where a very high degree of regularity was required, especially in telegraphic and astronomical apparatus, and it was more particularly with a view to these that he had constructed the more delicate modification of the governor as applied to the clock now exhibited.

The earlier form of the chronometric governor with the conical pendulum had been designed by himself several years previously, but was open to the great objection of being complex and rather delicate; and having lately taken up the subject again, he had been led to the improved construction now described, the action of which was exceedingly quick on the slightest alteration of speed in the engine, having a considerable advantage in this respect over the earlier governor, so that an engine could now be kept working with remarkable regularity.

The CHAIRMAN enquired whether the delicate governor now exhibited at work in connection with the electric clock was capable of showing the effect of any sudden alteration in the resistance to the driving power of the clock.

Mr. SIEMENS showed that the slight increase of friction produced by the pressure of a finger upon the driving spindle caused the cup of the governor to rise out of the liquid so that the overflow diminished, and ceased altogether if the friction were sufficiently increased; but the speed of the governor remained precisely the same as before, the increased power absorbed by the friction being compensated by the diminished resistance offered by the revolving cup of the governor. On removing the friction from the driving spindle the cup again sank to the proper depth in the liquid, and the overflow began again, while the speed still remained unaltered.

The CHAIRMAN enquired whether the action of the governor as applied to steam engines would be sufficiently prompt in the case of marine engines to check the engine at once, supposing the pitching of the vessel caused the screw ever to be raised out of the water altogether, as not unfrequently happened in a rough sea.

Mr. SIEMENS thought the action of the governor would be quite quick enough to meet such a case; for he had found the governor regulating the engine at his own works acted so promptly that even if the whole work was suddenly thrown off the engine no visible effect was produced on the speed of the flywheel.

The CHAIRMAN enquired what size of revolving cup would be required for the governor of an engine of large power; he supposed the size would be considerable for an engine of 1000 horse power.

Mr. SIEMENS thought that for an engine of 1000 horse power the cup of the governor would not have to be more than 15 inches diameter at the very utmost; and probably a 12 inch cup would be found quite sufficient.

Mr. E. A. COWPER said he had seen the governor at work upon the engine at Mr. Siemens' works at Woolwich, and had made an experiment to test its quickness of action in controlling the speed of the engine. A heavy plank of wood was applied as a lever against the rim of the flywheel, so as to act as a break, and the outer end was weighed down until the engine had just as much work upon it as the steam was capable of doing when the throttle-valve was full open. The break was then suddenly released altogether, so that the whole work was suddenly thrown off the engine, yet there was not the slightest difference to be perceived in the speed of the engine; and this appeared so surprising that he had repeated the experiment several times, but with the same result in each case. This was precisely a similar case to that of the screw propeller of a vessel being suddenly lifted entirely out of the water, and there was therefore no doubt that the governor would be applicable with complete success to marine engines, being absolutely instantaneous in its action; for it did not require that there should be a considerable increase of speed in the engine before it would act, but it acted directly and closed the throttle-valve at once, because as soon as the engine overran the governor at all it began to close the throttle-valve.

Mr. F. J. BRAMWELL observed that he had also had an opportunity of seeing the governor at work, and it was certainly as efficient as any governor could possibly be in keeping the engine constantly at one uniform speed. He had himself had an oppor-

tunity of judging of the efficiency of the principle of the governor from having employed a modification of the former chronometric governor for the purpose of regulating the speed of an engine driving rolls for rolling iron; and he had found that in this case the action of the governor was perfectly satisfactory, as the only difference observable when the work was thrown on the engine by a very heavy piece of iron passing through the rolls was that an increased volume of steam issued from the exhaust pipe, the speed of the rolls remaining unaffected. The efficiency of the governor in that case had proved so complete that he had since put up another to control an engine having the most irregular work to perform, and this second governor had also worked very well indeed. In that form of the governor however there was no doubt that the uniformity of its action was somewhat dependent upon the constancy of the friction, and some attention was therefore required to ensure the friction being maintained always the same. But the improved construction of governor now described, having the revolving cup of liquid substituted for the conical pendulum, required no attention to ensure its efficient working, as its action did not depend upon delicacy of adjustment nor uniformity of lubrication of surface, and therefore it was not liable to get out of order. The application of the governor to the electric clock now exhibited might perhaps lead to the notion that it was only suitable for such applications, and was too delicate for use as a steam-engine governor; but this extreme test of application to a clock only served to show the complete correctness of the principle, and did not in any way prove that the governor was unfitted to control an engine. The fact was that in the extent of its applicability the governor was as universal as the steam hammer, which would forge a large mass of iron or only crack a watch-glass. The governor could accordingly be used either as an absolute measurer of time for the most delicate chronometric purposes, according to the more refined mode of construction (shown in Fig. 1), with the revolving cup arranged to rise or fall upon the driving spindle; or if constructed according to the simpler plan (shown in Figs. 3 to 5), for use as a steam-engine governor, it still secured practical regularity of motion,

the action being instantaneous upon the slightest alteration of the load.

As an illustration of the way in which the speed of the governor was independent of the gravity of the liquid employed might be named the fact that, if a water wheel were to be turned by a stream issuing from a cistern having a given constant head, the speed of the wheel would clearly be the same whether water or mercury were used, although the power would be much less in the former case than in the latter. Similarly the speed of the governor was not affected by the specific gravity of the liquid employed in the revolving cup, but its power might be augmented without altering its size by increasing the specific gravity of the liquid; and the difference in the specific gravities of mercury, water, paraffin oil, and spirits of wine, afforded therefore an ample range for varying the power of the governor according to the amount of resistance which it had to overcome in working the throttle-valve of the engine. It had been shown in the paper that the power of the governor now exhibited, having a cup of 6 inches diameter and working with water, would be sufficient to move a resistance of 38 lbs. through 6 inches in 5 seconds, with an increase of speed in the governor itself of only about 2 per cent.; and as it was only during the time occupied by the governor in acting upon the throttle-valve that any change could take place in the speed of the engine, it followed that in the case of an engine running at 60 revolutions per minute and regulated by a governor of this size, the total absolute change that could be produced in the engine would be only that it would make one tenth of a revolution more or less than the proper amount, after which it would immediately resume its original speed, in consequence of the throttle-valve having by that time become correctly adjusted by the governor.

As regarded the size of the governor, it would be observed that the outside diameter of the chamber containing the revolving cup of liquid was not so great as that of an ordinary two-ball governor such as would be employed upon an engine of the same power, when the balls were at rest; and as the space occupied by the new governor did not increase by its being put in motion, the room

required by it when in action was less than half that taken up by the ordinary ball governor when the arms were opened out by its revolution.

Mr. W. FAIRBAIRN considered the chronometric governor was an exceedingly ingenious contrivance, and would be highly valuable for all purposes where great regularity of motion was required. He had himself employed one of the former chronometric governors with the conical pendulum on one of the engines at his works in Manchester for many years, and it was found to answer exceedingly well; ultimately however it had fallen into disuse, not from any defect in the principle of the governor, but simply from the engineman not taking the requisite care to keep it in proper order, so that the friction could no longer be relied upon as definite. There was no doubt however that the governor might be considered successful in giving a uniform motion to steam engines, and also to astronomical instruments, as shown by the fact of its being employed by the Astronomer Royal for regulating the motion of one of the equatorial telescopes in the Greenwich Observatory. In the small governor now exhibited at work upon the electric clock he observed that the revolving cup was connected to the driving spindle by a light spiral spring, which allowed for the vertical movement of the cup in working; and he enquired what took the place of this spring in the other form of the governor as applied to steam engines.

Mr. SIEMENS explained that in both the forms of the chronometric governor described in the paper the fundamental principle of action was the same, namely that the resistance offered by the liquid raised in the cup was employed as the governing power for effecting the control of the speed; but the different mode of applying this power for the purpose led to the difference of construction in the two forms of the governor. In the delicate governor employed upon the electric clock, the revolving cup was driven directly by the driving spindle through the spiral spring, and the bush by which the cup was carried upon the spindle was a quick-threaded screw; so that when the proper speed was exceeded the cup dipped deeper in the liquid and took up a larger quantity, whereby the resistance

to the driving power was increased; while any slackening of speed below the proper amount caused the cup to rise partly out of the liquid, and the resistance was diminished to a corresponding extent. In the steam-engine governor on the other hand the revolving cup was not driven by the engine at all, but by the constant weight upon the lever of the throttle-valve spindle; this weight was constantly trying to fall, while the engine was constantly trying to lift it through the differential wheels. These wheels were geared together in the proportion of four to one, so that the governor cup made four revolutions for one of the engine. The cup however had no vertical motion in this case, but the effective resistance of the liquid overflowing from it was increased by the set of fixed vanes placed round the circumference of the external chamber and the corresponding set of blades fixed round the outside of the cup. The throttle-valve weight acted upon the centre pinion of the differential gearing, and the pinion was allowed to yield to the weight, but only at the fixed velocity determined by the resistance of the liquid to the revolving cup. Hence if the engine attempted to go faster than the proper speed allowed by the governor, it would wind up the weight faster than the governor allowed it to fall, and the throttle-valve would instantly be partially closed by the weight lever acting direct upon it; while if the engine failed to wind up the weight fast enough, the governor would let it fall, and the throttle-valve would be further opened; so that in either case the speed of the engine was at once brought back to the proper rate. If the speed of the revolving cup could be kept absolutely constant with the regularity of a clock, it would oblige the engine to run with the same absolute regularity; but though the power necessary to enable the governor to perform the work of moving the throttle-valve could only be obtained by an actual change of speed for the moment, it had been shown that in practice sufficient power was obtained for this purpose, even when the liquid employed was only water, without the speed of the engine being allowed to vary from the proper rate beyond an amount that was so small as to be altogether inappreciable.

Mr. FAIRBAIRN observed that, if the desideratum of a regular uniform motion for a steam engine could be attained under all

the irregularities of the work, a very important point would be accomplished; and from the particulars which had been given respecting the working of the new governor there appeared to be no doubt that this object was now effected, and he should be glad to have an opportunity of seeing the governor in actual work. He enquired whether there was not some little difficulty in practice from the evaporation of the water in the governor, and what means there was of keeping the supply always up to the proper level; and also whether mercury had been tried instead of water, and what difference in the working of the governor was found in that case as compared with the use of water.

Mr. SIEMENS replied that the level of the water in the governor was shown by a glass gauge tube fixed on the side of the chamber containing the revolving cup, and alongside the tube was a scale, upon which were marked the number of revolutions per minute of the engine corresponding to the different levels of the water; the addition of water caused the speed of the engine to be diminished, and a reduction of the quantity allowed of a higher speed. The chamber containing the water was closed at the top, so that no evaporation could take place; and the only place where any escape of vapour could possibly occur was through the centre bearing of the driving spindle, which was made sufficiently easy for the spindle to run freely; but as there was no circulation of air through this bearing, there would in practice be no escape of vapour through it. He had not tried the use of mercury in the governor, but the specific gravity of the liquid had no influence on the speed of the revolving cup, although the power of the instrument for overcoming the resistance of the throttle-valve was increased by an increased density of the liquid; so that the specific gravity of mercury being fourteen times that of water, a governor working with mercury would have fourteen times the power of one of the same size in which water was used.

Mr. FAIRBAIRN enquired whether the power of the governor was not affected by the quantity of water contained in the chamber in which the revolving cup worked.

Mr. SIEMENS explained that the quantity of water did not affect the power of the governor but only its speed, since the amount of

the overflow regulated itself according to the speed at which the cup was driven; and therefore supposing, while the engine and governor were running at the proper speed, the quantity of water in the chamber was suddenly increased by the addition of more water, the only result would be that more water would be taken up by the revolving cup and a larger overflow would be produced, which would instantly increase the resistance to the rotation of the cup, and cause it to run at a lower speed, thereby reducing at the same time the speed of the engine to the lower rate corresponding with the larger quantity of water. The water was in reality a liquid break, which absorbed instantly all the surplus power that might be applied to drive the governor, and thus kept the speed of rotation of the governor practically the same at all times.

Mr. W. M. NEILSON suggested that a small pneumatic water feed might be attached to the governor for preserving a constant level of water, if there were any possibility of water being lost by evaporation or leakage; as it would be very inconvenient to find the speed of the engine becoming increased by a gradual diminution in the quantity of water contained in the governor.

The CHAIRMAN enquired how long the governor had been found to continue in work at the proper speed without requiring any renewal of the water supply.

Mr. SIEMENS replied that the governor had never been touched for the purpose of adding water to it since it was first put to work in October last; and he had not thought it necessary to pay any attention to the water supply after first starting, because he considered it utterly impossible that the water could find its way out, the chamber of the governor being closed.

The CHAIRMAN enquired whether it was intended for the outside chamber containing the revolving cup to be made of glass, as in the governor now exhibited upon the electric clock.

Mr. SIEMENS replied that the outside case of the steam-engine governor was made of cast iron; and in the electric clock now exhibited it was only made of glass for the purpose of allowing the working of the governor to be seen.

Mr. F. J. BRAMWELL remarked that in the case of applying the governor to marine engines the pitching of the vessel would

interfere with the effect of the weight upon the throttle-valve lever, by which the revolving cup of the governor was in effect driven; and he suggested that the difficulty might be obviated by substituting a spring in place of the weight.

Mr. SIEMENS said it would certainly be necessary to employ a spring instead of the weight on the throttle-valve lever, in applying the governor to marine engines.

Mr. C. E. AMOS remarked that he had tried the previous form of the chronometric governor, with the conical pendulum and friction break, and could bear testimony to its complete efficiency and perfect accuracy in keeping the speed of the engine correctly to the proper rate, so long as the friction break continued in proper order. The practical difficulty however was the lubrication of the break; and as there was not the means of ensuring its being kept uniformly lubricated, the governor ultimately went out of use. But in the new governor now described, the correctness of its action did not depend upon friction, but upon the resistance produced by the liquid overflowing from the revolving cup; and he therefore thought the new governor was not only a very good one in principle, but would prove thoroughly successful in practice. With regard to the application of the governor to marine engines, he enquired whether the disturbance occasioned in the liquid by the vertical pitching of the vessel would not materially affect the proper working of the governor.

Mr. SIEMENS replied that the oscillations in the liquid in consequence of the pitching of the vessel would be by no means so extensive as might be imagined; this was shown already in the case of the ship's compass, which floated on water without exhibiting any excessive amount of motion, and the water was subject in that case to exactly the same variations in level that would occur in the governor. Moreover the bottom of the chamber containing the revolving cup might be made hemispherical, with the apex of the cup in the centre, in which case the oscillations of the liquid in the chamber would not affect the depth of immersion of the cup at all. The principle of gyration in fact counteracted the effect of gravitation, and the overflow from the rim of the cup would remain

uniform whether the axis of the cup were vertical or tilted. A sudden vertical pitching of the vessel could only have the effect of very slightly increasing the force of gravitation in pitching upwards, and very slightly diminishing it in pitching downwards, tending in the former case to diminish the overflow from the revolving cup, and in the latter case to increase it. But the mean result would be the same as if no pitching took place, inasmuch as the governor cup had a considerable momentum in revolving; and therefore even if any such irregularities occurred in the overflow they would perfectly compensate themselves, without affecting the speed of the governor.

Mr. E. A. Cowper observed that an important feature in the new governor was the facility that it offered for varying the speed at which the engine was to run, as it was only necessary to alter the level of the water in the governor by means of the gauge glass at the side, in order to change the speed to any different rate; the addition of water would reduce the speed to a lower rate, or the speed could be increased by running off some of the water out of the governor.

Mr. C. E. Amos remarked that the same object might also be accomplished by shifting the weight upon the throttle-valve lever, if that were preferred, without altering the water level in the governor.

The Chairman thought the new governor was a most important invention, and would prove invaluable for all purposes where perfect uniformity of motion was required; and he did not see why it should not be generally used for marine engines just the same as for stationary engines.

He proposed a vote of thanks to Mr. Siemens for his paper, which was passed.

The following paper, communicated through Mr. Sampson Lloyd, was then read:—

ON AN IMPROVED CONSTRUCTION OF WROUGHT IRON TURNTABLE.

By Mr. WILLIAM BAINES, of Soho.

In the improved construction of Wrought Iron Turntable, forming the subject of the present paper, the object of the writer has been to obtain a turntable made entirely of wrought iron, but with uniform depth and strength throughout the top; and with all the portions combined together solid, like an ordinary cast iron top, thereby preserving the stiffness and solidity of a cast iron table together with the toughness and strength of wrought iron. This construction further gives the advantage of great saving in weight, and facility of conveyance; as the top of the table takes entirely to pieces, instead of being composed of bulky castings.

The construction of the turntable is shown in Figs. 1 to 4, Plates 5, 6, and 7. Fig. 1, Plate 5, is a vertical section of a 12 foot table; and Fig. 3, Plate 6, is a plan of the same table. Fig. 4, Plate 7, is a plan of an 18 foot table.

The top of the turntable is constructed entirely of wrought iron girders, formed of bars rolled to a special section, as shown in Fig. 8, Plate 10, drawn half full size, so as to fit into one another when placed together side by side; and these are framed together in such a manner as to form a continuous rigid girder in all directions, as shown in the plans, Figs. 3 and 4. The section of one of the combined girders is shown at AA in Fig. 1, and also drawn half full size in Fig. 9, Plate 10. Only one form of section of iron is employed, as shown in Fig. 8, the bar being rolled with two ribs and a groove or channel between them, running along one edge of the plate and upon both sides, and a single rib and groove of the same pitch running along the other edge of the plate on both sides; so that by reversing the bars alternately top and bottom edge upwards, as shown in Fig. 9, the ribs and grooves fit into one

another with complete accuracy, and the several bars are thus checked into one another along their entire length, as seen in the specimens exhibited. The bars are $7\frac{1}{4}$ inches depth and $\frac{3}{8}$ inch thickness, weighing 12 lbs. per foot.

In this arrangement the bolts which secure the bars together are all of them merely fishing bolts, having simply to hold the bars together laterally, without being exposed to any transverse strain; as the bars are held from sliding upon one another vertically by the ribs and grooves along their edges, thereby relieving the bolts from all transverse strain. The bars can thus be cut into pieces of any length required, and then joined together in any lengths and at any places by bolting them together; and they then form a single continuous solid girder of uniform depth throughout.

The use of this ribbed and grooved section of bar for constructing the girders of the table allows of increasing the strength of the girders towards the centre of the table without increasing their depth, by the insertion of an additional bar in the length nearest to the centre, thus increasing the thickness of the girders towards the centre, as seen in the plans, Figs. 3 and 4. Thus in the plan of the 12 foot table, shown in Fig. 3, the four main girders BB radiating from the centre pin are each composed of three bars bolted together; but beyond the points where they cross the lines of rails on the table, the middle bar alone is continued straight onwards to the rim of the table, while the two side bars are turned off at 45° on either side, to form the girders for carrying the rails above; and these side bars are further strengthened for the purpose by means of the additional pieces CC bolted to them, as shown in the plan. Moreover the same construction affords the means of making the solidity of the structure continuous throughout the entire framing of the top of the table, as effectually as if the framing were all in one single casting. For it will be seen from the plan, Fig. 3, that while the middle bar and one side bar in each of the four ribs B form the arms of one quadrant of the circle, the other side bar is carried into the next quadrant, whereby the four quadrants are successively connected with one another all round the circle.

The position of the girders forming the top of the turntable is arranged to coincide with that of the rails, which are carried upon the top of the girders, and are bolted down upon them by countersunk bolts passing down through the space between the bars of the girders, as shown by the dotted lines at DD in Fig. 1. The rails are thus independent of the structure of the turntable, and can therefore be readily renewed in the same manner as ordinary rails when worn out, without requiring any portion of the turntable to be taken to pieces for the purpose, as they form no part of the framing of the table.

The outer rim EE, Fig. 1, of the turntable top forms the upper roller path, and is constructed of bar iron rolled to the section shown half full size in Fig. 10, Plate 10, ribbed and grooved along the inner edges to correspond with the bars forming the girders. This bar is bent to the required circle of the rim, and the ends are fished together with a butt joint, with outside and inside cover plates. There is no turning required for the face of the roller path, as the rolled bar iron is sufficiently true for the purpose, having as true a surface as the ordinary railway rails. The lower roller path is an ordinary T rail bent to the proper circle and laid upon timber sleepers. The rollers FF are of cast iron, and the live roller frame consists of a ring of plain bar iron, with an external bracket bolted on at each of the rollers, the roller spindles being connected to a ring turning loose round the centre pin.

The centre pin G, Fig. 1, and the foundation plate or socket carrying it, are of cast iron. The top end of the pin is bored out, as shown enlarged in Fig. 2, and a piece of wrought iron I, faced with steel, is let in, to form the centre bearing for the top of the turntable. The surface of the steel is spherical, bearing against a corresponding spherical chilled surface on the under side of the cast iron cap H, to which is bolted the centre cross J of the turntable top. The space left in the recess at the top of the centre pin forms an oil cup, for lubricating the bearing surfaces. The only cast iron employed in the table is therefore for the rollers and for the centre pin and connections. The centre cross J, which was

previously made of cast iron, is now made of wrought iron in a single forging, as shown in Figs. 6 and 7, Plate 9, with the advantage of greater strength and lightness. The wrought iron centre piece consists of a strong welded tube, bored out to fit the centre pin G of the turntable, and grooved outside on the four sides to receive the ribs of the bars composing the girders, which are bolted to it with countersunk bolts, as shown in the drawing. The four suspending bolts for the turntable top lay hold of a wrought iron washer plate K underneath.

The bars composing the girders of the turntable top are bent hot by hydraulic pressure, as shown in the plan, Fig. 12, Plate 11. Where two or more of the bars have to be bent to fit one another, they are made to fit by simply bending one upon the other in their permanent position, the bar first bent forming then the block for bending the second upon, and so on, which ensures each one being thoroughly bedded upon the others. The same die L is made available for bending all the bars, by having one jaw of the die formed of a sliding block M, which is adjusted by a hand screw to suit each successive increase of width of the bend in the outer plates, the die L itself being loose from the ram of the hydraulic press, so as to slide laterally to the extent requisite with each successive increase of width in the jaw. The correct position of the bend is ensured by the simple means of the fixed stud N, which enters the permanent bolt hole previously punched in each bar; and the only alteration required in making turntables for different gauges of railway is the shifting of this stud into the proper hole for the particular gauge, according to the positions indicated upon the drawing for the several gauges of railway. By this simple arrangement for bending the bars, the whole of the bars are bent for the turntables for all gauges of railway, without the need of a single pattern of any description; the proper length of the bars being determined by templates, to ensure complete uniformity throughout the work. The ends of the bars are heated for bending by a portable forge, shown in the sectional plan, Fig. 13; and Fig. 14 shows the mode of bending the ends that have to be united to the rim of the turntable, by means of the long hand-lever P.

There is a great saving of weight in the present wrought iron turntable, the weight of which is less than one half that of cast iron tables of the same size :—

the 12 foot turntables weigh only				3½	tons	instead of	7½	tons
„	15	„	„	„	4½	„	„	10½ „
„	18	„	„	„	5½	„	„	13 „

This saving of weight is an important advantage in reducing the labour of fixing and removal; and the tables can be readily moved and loaded or unloaded, without the tackle requisite for the heavy castings of the ordinary tables. In sending the tables to distant countries not only is the total freight and cost of conveyance reduced two thirds, but in consequence of the construction of the tables admitting of readily dividing them into portions all of small weight, great facilities are afforded for conveying them into difficult situations.

The reduction in weight also renders the tables easier to turn, and thereby diminishes their wear and tear; the weight of the turntable top in comparison with a cast iron top being

in the	12	foot table		1¼	tons	instead of	2¼	tons
„	15	„		2½	„	„	4½	„
„	18	„		3½	„	„	7¼	„

The depth of these turntables is considerably less than in most other tables, being only 20 inches total depth both in the 12 foot and 18 foot tables, in consequence of the compactness of the construction. The depth of the pit and excavation for the foundations are therefore proportionately diminished, which is an important advantage in situations where drainage is difficult.

This turntable has a special advantage in facility of construction and adaptation to different circumstances, as compared with the cast iron tables and those constructed of wrought iron and cast iron combined. In those cases patterns are required for the castings, and a different pattern is necessary for each different size of turntable, however small may be the difference in diameter; a different pattern is also necessary in each size of table for every different gauge of rails and for every variety in position of the rails,

whether a single line of rails, or double lines at right angles, or with oblique lines at 45° or 60° inclination. The cost and time of construction is thereby materially increased in the cast iron tables, causing delay in producing any tables adapted to meet special circumstances, and seriously increasing the expense where a few only are required of the same kind.

In the wrought iron turntable now described these difficulties are entirely removed. As the table consists of merely a repetition of the same pieces, varying only in length and angle of bend, any desired alteration in diameter is readily effected, however fractional in amount, by simply altering the lengths of the bars accordingly, without affecting the construction of the joints. The table can also be made to suit any direction or number of the lines of rails, by making the angle of the bends and the lengths of the bars to correspond; and the same facility applies also to the adoption of any gauge of rails. In Fig. 5, Plate 8, is shown a plan of a four-line turntable having four lines of rails inclined to one another at 45°, showing the mode of arranging the bars in the turntable for carrying each of the lines of rails.

In Fig. 3, Plate 6, is shown the most general arrangement of turntable with two lines of rails at right angles for a main line turntable; and in Fig. 4, Plate 7, is the arrangement with a single line of rails for engine turntables. A similar construction is applicable when a double gauge of rails is required on each of the two lines at right angles, as in the case of combining the ordinary broad and narrow gauges of this country. In the case of one of these double-gauge tables, originally constructed and laid down to accommodate both the broad and the narrow gauge, it has subsequently been determined to abandon the broad gauge, and to run the narrow gauge rails central across the turntable, according to the ordinary plan; and this construction of table affords the greatest facility for effecting any such modification, the rails being supported in their new position by the simple addition of a few bars. In the case referred to, these bars have only to be sent to the turntable, ready cut to their proper lengths and bent to the proper angles, and to be inserted in their places in the table, without

requiring it to be taken up for the purpose, and without delaying the traffic longer than is requisite for drilling the bolt holes and bolting the bars in, which can be done at intervals according to convenience.

These tables are now being manufactured for five different gauges of railway, and of all the different sizes in general use, without employing any patterns whatever for the different sizes and forms; all that is required being the templates for diameter of circles and lengths of the several pieces of which the table is composed.

These tables have been at work more than three years, and exposed to the severest tests of working; but no failure or fracture has occurred in them or any sign of injury, although in the same time with cast iron tables there would unavoidably be considerable failure from breakage. One of the 12 foot tables on this construction has been tested with a load of 40 tons, and one of the 18 foot tables with a load of 50 tons, without the slightest injury resulting to the tables.

Mr. BAINES exhibited sections of the bars composing the girders of the turntables, and also a segment of one of the turntables, showing the mode of framing the bars together.

The CHAIRMAN enquired how many of the turntables on this construction were now at work.

Mr. BAINES replied that there were now about 100 of the turntables at work, and they had proved so satisfactory that in every case where the new tables had been tried, their use had been extended.

The CHAIRMAN enquired whether the same construction would answer for the turntables now necessary to be used in turret ships, which were required to be about 25 feet diameter and to carry a weight of about 200 tons. He thought if the wrought iron turntables

could be adapted for that purpose they would be very advantageous, on account of their lightness in comparison with the present heavy cast iron tables. The present tables were usually made to turn upon stationary rollers fixed on the deck, instead of live rollers running round in a frame, as shown in the drawings.

Mr. BAINES replied that one of the wrought iron turntables of 12 feet diameter, composed of bars $7\frac{1}{4}$ inches deep, would readily carry a load of 100 tons without injury; and there would therefore be no difficulty in making tables of 25 feet diameter to carry 200 tons, by using bars of greater depth and thickness for the purpose. Such tables would have the great advantage of being very simple to repair, as they could be easily repaired in a very short time if disabled in war.

The CHAIRMAN enquired whether there had been any difficulty in rolling the bars of the particular section shown in the drawings; and whether the rolling was done with sufficient accuracy to ensure the bars going together correctly in constructing the turntables.

Mr. BAINES replied that the rolling was found to be done with complete accuracy, and it would be seen from the sections now exhibited of the girders that the bars went together with perfect correctness, fitting tight into one another when put together just as they came from the rolls, as the ribs and grooves in the successive bars corresponded exactly to one another and their surfaces were quite smooth and clean.

Mr. R. WILLIAMS said they had now rolled about 100 tons of the bars of that section at the Patent Shaft Works, Wednesbury, and had found no difficulty in rolling them with the required accuracy for enabling them to fit correctly into one another in bolting together. The ribs running all along each edge of the bars made a very strong section of iron, and he suggested that such a section was peculiarly adapted for the construction of wrought iron girders generally, and might be applied very advantageously in warehouses and similar buildings. Such girders would be made with no waste of iron in cutting to lengths or welding, and could be constructed of any length without the necessity of welding, as the ends of the bars simply required to be put together with a butt joint, and the joint

was then securely fished on each side by an external cover plate. The strength in this construction could also be increased to any extent by simply increasing the width of the girders by the addition of any number of bars, and the greatest strength was obtained at the parts where it was required, in the top and bottom of the girders; moreover the expense of labour in making girders on this principle was the least possible. Another advantage was that the outside bar of the girders might be rolled externally of any special section that might be desired for ornamental purposes; just as in the turntables shown in the drawings, the bar forming the circumference of the tables was rolled to the particular section shown, in order to form the upper roller path: and two of these bars bolted together back to back with an intermediate bar between, as shown in Fig. 11 and in the specimen exhibited, formed a double-edged angle-iron section, which could also be used for the purpose of running over rollers. This ribbed section of iron was on the whole the simplest and best section he had yet seen for general purposes of iron construction, such as shipbuilding, warehouse girders, and railway purposes; and for the sole plates of railway rolling stock it might also be advantageously employed.

Mr. W. M. NEILSON considered the section of iron was certainly a very good one mechanically, and very cleverly designed for making the ribs and grooves fit together with such nicety by simply inverting the same section of bar.

The CHAIRMAN enquired whether it was thought that girders put together in the manner that had been described with butt joints would be as strong at the joints as in the solid.

Mr. R. WILLIAMS replied that the butt joints were made really the strongest parts of the girders by the addition of the external cover plates on each side of the joint; and it must be borne in mind that these cover plates, being made of the same section of iron, were not like ordinary plain cover plates, where the strength of the joint depended upon the security of the bolts or rivets by which the cover plates were secured; but the ribs and grooves caused the cover plates throughout their entire length to be checked into the main bars of the girder, and thus made the strength even greater

at the butt joints, while the bolts simply held the plates together, without being themselves subjected to any transverse strain. No welding was therefore required in putting the girders together, whatever length might be required, and the risk of failure through defective welding was thus obviated.

Mr. E. JONES said the wrought iron turntable described in the paper was the best and strongest turntable for its weight that he had ever met with; and they were now making a large number of these tables at the Old Park Iron Works, Wednesbury, to go out to India.

Mr. J. PETTIFOR enquired what was the cost of the new turntables, exclusive of the foundation, in comparison with that of the ordinary cast iron tables of the same size.

Mr. BAINES replied that the cost of the wrought iron turntables was about the same, but the strength was three times as great as that of the ordinary cast iron tables of the same size.

Mr. E. A. COWPER thought the construction of the wrought iron turntable was highly ingenious, having the bars of the girders joggled into one another continuously throughout their whole length, so that the bolts were merely fishing bolts with but little strain upon them. This mode of construction gave the means of increasing the strength of the girders at the parts where required; and it was seen from the drawings that towards the middle of the table the girders were composed of three bars bolted together, while at the outer ends there was only a single bar. The only point in the construction which appeared to him of doubtful propriety was the curving of the bars at the centre for uniting to the centre boss, because the curved girders would be somewhat similar to springs, and some complication of strains might be thereby introduced. A certain amount of deflection under a load however seemed desirable, and he thought some of the deep cast iron turntables at present in use were probably too rigid. He enquired what had been found to be the deflection of the wrought iron tables under a load.

Mr. BAINES replied that he had not measured the deflection of the wrought iron turntables, but it was certainly very slight, as proved by the fact that the tables were easily turned round under

the load by two men, because the facility of turning depended of course upon the stiffness of the girders, by which the load was prevented from coming too heavily upon the rollers of the table. With regard to the curving of the bars at the centre of the table, the object of this had been to make the girders continuous in all directions throughout the table, which was rendered possible in this construction of table in consequence of each girder being composed of several separate bars bolted together. By this means also the girders were united to the casting forming the centre boss. In one of the earliest tables put to work the centre casting had been a very light one and had been broken; but it was so securely held in its place that it had still been kept at work, and had continued so for three years under a heavy traffic without any difference, and it had not been thought worth while to replace it by a new casting. As it was desirable however to avoid any risk of accident by breakage of the centre casting, he had now adopted a wrought iron centre instead, as shown in the drawings, so that the entire moveable top of the turntable was now made of wrought iron.

Mr. E. A. COWPER enquired whether it was intended to weld the bars of the girders to the wrought iron centre, so as to make a solid forging in the centre; this would probably make a very sound job.

Mr. BAINES explained that there was no welding, but the wrought iron centre boss was simply grooved on the four sides to receive the ribs of the bars, which were then securely bolted to it in a similar manner to the other joints of the table.

The CHAIRMAN moved a vote of thanks to Mr. Baines for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Nineteenth Anniversary of the Institution.

PROCEEDINGS.

3 MAY, 1866.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 3rd May, 1866; HENRY MAUDSLAY, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

WILLIAM BAINES, . . .	Soho.
CLEMENT BARNARD, . . .	Birmingham.
RESTEL R. BEVIS, . . .	Birkenhead.
ANDREW BETTS BROWN, . . .	London.
CHARLES CLEWORTH, . . .	Jumalpore, India.
WILLIAM DANIEL, ...	Shrewsbury.
WALTER FIDDES, . . .	Bristol.
CHARLES DOUGLAS FOX, . . .	London.
GEORGE HADEN HICKMAN, . .	Tipton.
CHARLES HODGSON, ...	Portarlington.
THOMAS HOLCROFT, . . .	Bilston.
JOHN C. A. HOUGHTON, . . .	Dudley.
JOSEPH FOSTER LLOYD, . .	Wednesbury.
RICHARD NORFOLK, ...	Beverley.
JOHN HARTLEY PERKS, . .	Wolverhampton.
ALEKSANDER SCHOLTZE, . . .	Warsaw.
FREDERICK TURNER, . . .	Ipswich.

The following paper was then read:—

ON THE CORROSION OF LOCOMOTIVE BOILERS, AND THE MEANS OF PREVENTION.

By Mr. WILLIAM KIRTLEY, of Derby.

From the reports of accidents with Steam Boilers in this country during the last year 1865, it appears that during that period 55 steam boilers have exploded, causing the deaths of about 56 persons and injury to a much greater number. Amongst these explosions there have been on the railways of the United Kingdom out of 7000 locomotives 11 boilers exploded, causing loss of life and injury in each case, and in addition serious destruction of property. Each of these explosions must have been occasioned either by defects of construction or material, or else by negligent supervision. It is intended in the present paper to consider only the subject of high-pressure boilers, such as those of locomotives; and as in the large majority of exploded locomotive boilers it has been found that the explosion has arisen from the plates of the boiler having become weakened by corrosion at particular places, it is the writer's object to describe the nature and extent of this corrosion, and to endeavour to show the causes of its occurrence, together with the means of prevention.

In the present ordinary construction of locomotive boilers with lap joints, as shown in Figs. 7 and 8, Plates 13 and 14, the wear by corrosion of the plates is found principally round the smokebox end of the boiler barrel, in the interior, opposite to the edge of the outside angle iron, as shown at AA in Figs. 1, 2, and 3, Plate 12, where an annular groove is found to be eaten out of the plates by corrosion. This grooving extends sometimes so deep into the plate that only a thin shell of metal is left on the outside at the bottom of the groove, as shown in Fig. 3, which is a full size section of an actual case of the grooving; and the corrosion takes place so rapidly in many cases that the plates require renewal after only a few years'

work. A similar grooving also takes place along the edge of the inside lap at the longitudinal joints, as at D and E in Fig. 6, and also at the transverse circular joints, as at BB in Figs. 4 and 5; but in the latter case the grooving does not occur so frequently nor is the extent of corrosion so great as at the smokebox end and at the longitudinal joints, as seen in the specimens exhibited of corroded plates from the different situations.

It has to be remarked first that this grooving is only found below the water line, showing that it must be due to the chemical action of the water on the plates; and the special point to be enquired into is the cause of this action being so remarkably concentrated at the particular lines where the grooving takes place. It will be seen from the specimens shown, which are taken from locomotive boilers that have been at work for various periods of from three years to as much as nineteen years, that some corrosion also takes place over the general surface of the plates; but this is very limited in extent compared to the grooving at the seams, and it occurs very irregularly, being apparently influenced by some irregularities in the structure of the plates, causing them to be pitted irregularly by the corrosion.

In the ordinary construction of locomotive boilers with lap joints, as shown in Figs. 7 and 8, Plates 13 and 14, the barrel of the boiler is constructed of three rings, each ring formed by two plates of 7-16ths inch thickness, rivetted with lap joints FF and HH. The general amount of lap is $2\frac{1}{4}$ inches for single-rivetted and $3\frac{1}{8}$ inches for double-rivetted joints. The smokebox and firebox are each united to the barrel of the boiler by an angle iron KK, Fig. 8, 3 inches or $3\frac{1}{8}$ inches wide, welded into a ring. General experience has shown that after five or six years' wear of these boilers the grooving action that has been described is developed at the joints and at the edge of the angle-iron rings.

Now the longitudinal strain upon the joints of boilers constructed in this manner tends to spring and bend the plates at the joints, when under pressure, into the form shown exaggerated in Fig. 9, in consequence of the plates not being originally in the line of strain,

as shown by the dotted line SS in Fig. 8, which it will be seen runs along the outer face of one plate and the inner face of the next. Also in the longitudinal joints of the barrel, shown at FF in Fig. 7, a similar mechanical action takes place, the strain acting in the true circle shown by the dotted line SS, springing and bending the plates at the edge of the joints, as shown at GG, each time that the boiler is under pressure. The continued alternation of expansion and contraction in the boiler causes the scale that is deposited upon the plates from the water to be continually broken off at the edge of the joints by the mechanical action of this springing and bending of the plates at the lines of the joints; and the plates are thereby laid bare at those parts and kept continually exposed to the corroding action of the water, instead of being protected from the action of the water by the deposited scale remaining attached to them.

Though the corrosion produced by the water is slow in action and but slight in effect on the rest of the boiler plates, which are protected by some deposit of incrustation remaining almost constantly upon them, it becomes very serious on an exposed raw surface of iron; and this action is particularly severe in the case of locomotive boilers, in consequence of the total quantity of water evaporated in a locomotive boiler being much greater in proportion to the surface of the plates than in stationary boilers. The particulars are given in the accompanying Table of the total work done and water evaporated during the time they were running, by the several locomotives of which specimens are now shown from the boilers; and from these particulars 10 million gallons of water may be taken as having been evaporated in a locomotive boiler during the five to eight years in which the plates have become corroded through. As this is nearly double the quantity evaporated in the same time by an ordinary stationary boiler having three times the surface of boiler plate exposed to the action of the water, the total work of the locomotive boilers may be considered as amounting to six times the evaporation per square inch of plate in the same time, and the total length of working as equivalent consequently to from thirty to fifty years' working of a stationary boiler.

Particulars of Locomotives from which Specimens of Corroded Plates were taken.

Number of Engine.	Years of Working.	Miles run.	Water consumed. Gallons.
99	8	83,349	1,462,774
121	11¾	334,711	5,874,178
123	12	290,380	5,096,169
141	8¼	268,679	4,715,316
162	8¾	255,042	4,476,967
187	8¼	229,099	8,041,374
235*	14	315,227	11,064,467
250	14¾	316,391	11,105,324
255	14	293,559	10,293,920
274	13¼	303,249	10,644,039
306	11¼	229,162	8,043,587
306†	6¼	142,808	5,012,560
369	10¼	246,956	8,668,155
375	3¼	67,072	2,354,227
388	8¼	180,985	6,352,573
410	6¾	158,801	5,573,915
422	8¼	231,035	8,109,328
658	18¾	249,672	4,381,743

* Flanged tube plate. † After renewal with thick-edge plates.

It must further be noticed that the pressure under which the locomotive boilers are worked is much higher than in the case of stationary boilers, and the injurious action caused by the springing of the plates at the joints is therefore proportionately increased; and taking the pressures at 35 lbs. per inch for the stationary boiler and 140 lbs. for the locomotive, this makes the action four times greater in the locomotive boiler from this cause, taking the increase to be only at the same rate as the increase in pressure. Hence as the action is six times greater from the previous cause, a total is given of twenty-four times as great an extent of injurious action in the locomotive boiler as in the stationary boiler in the same length of time. As an illustration of the effects of increased pressure in increasing the corroding action, it may be mentioned that this grooving of the plates has been found to be materially increased in

amount since the working pressure of locomotives has been increased from 100 lbs. up to the present 140 lbs. per inch.

In some of the older classes of locomotive engines the writer has found that there is an increased local action of serious amount caused in the boilers by the rigid points of attachment to the boiler barrel, such as frame stays, brackets, &c., which offer special points of resistance to the expansion of the boiler when under pressure. A specimen of this grooving, taken from No. 187 engine in the preceding Table, is shown at CC in Figs. 4 and 5, Plate 12, caused by the rigid attachment of the spectacle-bracket M to the boiler barrel. The result is made worse when the firebox is rigidly fixed to the frames, or not allowed full freedom for expansion by the provision of a sliding bracket; as a great additional strain is thereby thrown on the tube plate, springing the angle irons round the ends of the boiler. The expansion of a 10 ft. 6 ins. or 11 ft. boiler barrel being about 3-16ths inch at a pressure of 140 lbs. per inch, an attachment to the frame at any other place besides the fixing of the cylinders and tube plate at the front end must subject the boiler to a bending strain at the points of attachment, causing a risk of corrosion at these points. In the Midland Railway engines all the other attachments except the smokebox angle iron are now removed, including that of the motion plate which carries the inner ends of the slide bars; and the boiler is allowed in expanding to slide freely throughout upon the frames.

In the longitudinal joints of the boiler the grooving from corrosion is generally found to be more marked when the inside edge of the lap faces upwards, as at E in Fig. 6, than when it is turned downwards, as at D. In the former case it may be considered that the deposit will collect upon the projecting ledge in larger quantities, forming a thickness of deposit sufficient to be detached bodily by the springing of the plate under pressure; and it will consequently leave the bare plate more frequently and extensively exposed to the direct action of the water, than when the edge of the plate faces downwards, as at D, because in the latter case the thinner film of deposit will not be so readily and frequently detached from the

plate by the same action. It must be borne in mind that the earthy deposit itself, being chemically neutral, cannot have any injurious action upon the plate; except in the case of a stationary boiler heated from an external flue, where undue heating and expansion of the plate are caused wherever its inner surface is separated from the water by any considerable thickness of non-conducting deposit.

In the preceding Table are given the particulars of seventeen locomotives on the Midland Railway, from which the specimens now exhibited of corroded plates were taken; showing the length of time of working and the mileage and consumption of water before the plates had become so defective as to require removal. The average result is $10\frac{1}{4}$ years' working, 255,645 miles run, and 7,618,778 gallons of water consumed by each engine.

In the case of the boilers constructed in the ordinary manner, as already described, the plates cut out show the grooving action of the corrosion below the water line, while they are comparatively clean above. In No. 235 engine the tube plate was flanged and rivetted inside the boiler barrel; and the result of working shows the advantage of this mode of construction over the ordinary angle-iron joint, since the plates at the smokebox end are not grooved along the end of the flange, as they would have been with an external angle iron.

From the foregoing consideration of the subject it therefore appears that the special corrosion of the plates at the joints is to be attributed to the combined operation of chemical and mechanical causes, the chemical action of the water in the boiler being concentrated upon those particular parts in consequence of the mechanical action produced at those parts by the strain upon the plates. That the combination of these two causes is requisite for producing this effect is shown by the middle of the plates being free from it, where they are exposed to the chemical action alone, without the mechanical action; and further by the joints in the upper part of the boiler above the water line being also free from it, where exposed to the mechanical action alone, without the chemical action. The removal of one of these causes will therefore be

sufficient; and in the locomotive boilers now to be described this object has been aimed at by removing the mechanical cause which produced the springing of the plates at the joints.

From the particulars already given of the corrosion which takes place in locomotive boilers, it appears that the greatest injury takes place at the smokebox end of the barrel, where there is not only a great and sudden change in the thickness and rigidity of the plates at the edge of the angle iron, as at J in Fig. 8, but also a leverage for the springing of the plate from the outer line of rivets, as at L in Fig. 9. The consequence is the bending of the plate at the point J, as in Fig. 9, each time of being under pressure of steam, owing to the outer line of rivets L being entirely outside of the line of strain S of the boiler plates. There is also a great tendency to injury of the angle iron, by this action tending to split it between the rivet holes at the outer line of rivets L.

The present plan adopted on the Midland Railway is found to obviate the injury previously experienced from corrosion; and this is accomplished by the use of plates rolled with thickened edges, as shown in section in Fig. 19, Plate 17, and shown exaggerated in thickness in Figs. 10 and 11. The ordinary thickness of 7-16ths inch is preserved in the body of the plate, and the edges are thickened to 5-8ths inch, with a long gradual taper in the thickness from I to I, Fig. 19, about 4 inches length. The effect of this long taper is that, when the plate is flanged, as at N, in order to do away with the angle iron, the taper ensures a gradual springing of the plate, distributed over all that length, instead of the sudden bending concentrated at one point, as at J in Fig. 9.

A similar section of thick-edge plate is also used at the transverse circular joints, as shown in Figs. 10 and 11, causing a gradual springing of the plates over a considerable length when under pressure, as in Fig. 11, instead of the former sudden bending at one point, as in Fig. 9. There is also an increased strength gained by this mode of construction, as the increased thickness of the plates between the rivet holes compensates for the loss of section by the holes.

The practical working of the thick-edge plates is shown by the specimen exhibited from No. 306 engine in the preceding Table. The original boiler of this engine, constructed in the ordinary manner, was removed after 11¼ years' working, as the plates were much grooved and pitted; and a new boiler constructed with the thick-edge plates was substituted, which has continued at work 6¼ years to the beginning of the present year. It was then found that the plates were free from grooving, although they were badly pitted.

A consideration of the ordinary construction of locomotive boilers and their defects shows that their construction admits of important improvement in the barrel, by removing the injurious strains resulting from the employment of lap joints, which throw the plates out of the line of strain, and by making the barrel truly cylindrical and circular throughout. These objects are effected by welding the longitudinal joints of the three rings forming the boiler barrel, and making these rings all exactly the same diameter, uniting them to one another with flush butt joints. This plan is now carried out upon the Midland Railway, as shown in Figs. 16, 17, and 18, and exaggerated in thickness in Fig. 12, Plate 15. The meeting ends of each ring are turned in a lathe, and united by covering strips O O, formed of welded flush rings, shrunk on over the joints and double-rivetted. Strengthening hoops P P are also shrunk on the centre of each of the plates, crossing the longitudinal welded joints, and are secured by a few rivets. These hoops and covering strips for the joints are carefully blocked before being shrunk on, and the whole of the rivet holes are drilled after the hoops are in their places.

These boilers are consequently truly cylindrical at all parts, and no strain to which they are subjected has any tendency to change their circular form. The effect of the longitudinal strain upon the transverse circular joints, as in Fig. 13, is found to be altogether inappreciable in practice, because the covering rings O O could not yield to it without contracting in circumference in the form of a double cone, Fig. 13; and on this account, together with their greater thickness, they offer a greatly increased resistance as compared with simple lap joints. All possible effect of the

longitudinal strain might indeed be entirely got rid of, if desired, by the further addition of inside covering strips at the butt joints, as shown in Figs. 14 and 15. At present the circular plates of these welded boilers are in two semicircular segments for the circumference of the boiler, and therefore require two welds; but the writer thinks the barrel of the boiler would be improved if each length were made of one plate only, whereby only one longitudinal weld would be necessary.

A remarkable corroboration of the correctness of this mode of construction is given by the samples exhibited from No. 658 engine, the boiler of which was constructed with butt joints all flush throughout, the transverse joints being covered by external hoops and the longitudinal joints by internal strips. This boiler has been at work nearly 19 years, having been started in 1847; but the engine being of smaller size than those now used with trains has only been employed as a spare engine for some years past. The plates of the boiler, which are the original ones and have never been repaired at any part, are all good, and the grooving has not taken place at the butt joints, a little irregular pitting alone being visible on the inside of the plates. The boiler has now been cut up only on account of the engine being abandoned from the great length of time it has been worked. The remarkable contrast shown by the freedom of the butt joints in this boiler from the grooving so universal with the lap joints in the ordinary boilers appears only to admit of being accounted for by the difference of construction of the joints in the two cases. In another engine of the same class, which was last broken up, after attaining the maximum mileage of 343,000 miles, the boiler plates were very badly grooved at the angle-iron joint at the smokebox end, showing that this part of the boiler remained as defective as in the ordinary boilers, the construction being the same as regarded this joint; while the rest of the joints being butt joints were free from the grooving.

The flanging, bending, and welding of the thick-edge plates for forming the boiler barrel are performed by the aid of machines specially designed for the purpose, which are shown in Plates 18 to 24.

The Flanging Machine is shown in Figs. 20 to 22, Plates 18 and 19. It consists of a horizontal table A, on which the thick-edge plate, shown black, having been previously heated, is laid and secured by clamps, being pushed forwards against the adjustable stop B, Figs. 20 and 21, so that the thick edge projects beyond the edge of the table to the required extent for forming the flange. The roller C is then brought down with a slow motion by the eccentrics D, as shown in Fig. 21, being firmly held by guides E at each end in the frame of the machine; and the edge of the plate is thus gradually bent down to form the flange. The table A is made to slide upon the bed F of the machine, and is set up by adjusting screws G to the required amount of clearance from the bending roller C, according to the thickness of the plate to be flanged. The front edge of the table is faced with a separate wrought iron or cast iron edge-piece I, which can be removed and changed for another having a different curve for the edge, according to the curve that is desired in the neck of the flange. The holding-down bar H is screwed down tight upon the plate, immediately behind the edge of the table, so as to hold the plate down flat on the table while the flange is being bent by the roller. The working speed of this machine is 7 double strokes per minute.

The Bending Machine, for bending the thick-edge plates into the semicircle to form the boiler barrel, is shown in Figs. 23 and 24, Plates 20 and 21. It consists of three horizontal rollers, of which the two lower ones AA are carried in fixed bearings at each end in the frame of the machine; while the third roller B slides vertically in the frame, and is lowered by the screws CC at each time of passing the plate through the rolls, to give the required degree of curvature to the plate. The screws CC were at first worked by hand, but are now driven by gearing from the main shaft. As the thickness of the body of the plate is only 7-16ths inch, while the thickness of the edges is 5-8ths inch, a liner plate 3-16ths inch thick is laid over the body of the boiler plate in the bending process, in order to make up the same thickness of 5-8ths inch throughout for passing through the rolls; and the liner plate is afterwards flattened again ready for subsequent use. At one end of each of the lower rollers AA is a

groove D to receive the flange of the plate; this groove is shown enlarged in Fig. 26, and is formed by a glut-piece or ring E, screwed upon the roller spindle F and tightened by a set screw G, by means of which the width of the groove can be increased or diminished according to the thickness of the flange of the plate. A corresponding groove is provided at the opposite end of the upper roller B, to allow of bending plates with the flange inside instead of outside. In order to obtain a sufficient hold upon the plate to pass it through the rolls, the surfaces of all the rollers are fluted longitudinally with shallow flutes at $1\frac{1}{4}$ inch pitch, as shown in Fig. 26, and enlarged to half full size in the section, Fig. 25. The lower rollers only are driven by gearing, the upper roller being merely a pressing roller for giving the required curvature to the plates, and weighing about 25 cwts. The working speed of the rollers is 3 revolutions per minute, or about 12 feet per minute speed of surface.

The two semicircular plates are then welded together into a single ring to form one length of the boiler barrel. The edges to be welded are first heated in the fire at A, Fig. 29, and upset sufficiently to give the required thickness of metal for forming the scarf weld. A welding heat is then taken on a short length of the joint of the plates, and the plates B are welded together along the joint upon the Welding Anvil, shown in Figs. 28 and 29, Plate 22. The anvil face C is shaped to the internal diameter of the boiler barrel, and is separate from the pedestal D of the anvil, so that it can be exchanged for other sizes of face, according to the diameter of the boiler. During the heating and welding, the plates B are held in the circular frame E, in which they are securely clamped; and the frame E being slung from a crane, the plates are readily handled. The two ends of the joint are first tacked together by welding, to secure the correct diameter of barrel, and the joint is then welded in short lengths from the centre towards each end.

The rings of the boiler barrel when welded up are blocked, to test them by stretching and bring them to the diameter of the boiler. For this purpose the rings are first heated in the Blocking Furnace shown in Figs. 30 and 31, Plate 23, having the fire-grate A under the centre, with six chimney flues CC round the

circumference. The ring B to be heated is put in from the top, and placed on end, with the heat from the fire passing up through the inside of the ring and then down all round the outside to the flues, so as to give a uniform heat to the ring.

The ring is then put on the Blocking Press, shown in Figs. 32 and 33, Plate 24; which is an ordinary hydraulic wheel-tyre blocking press, worked by a centre cone D forcing out the blocking segments EE. These blocking segments are carried up for the purpose and strengthened by brackets, as shown in the drawing. One half of the height of the ring B is blocked at once; and the ring is then turned over for blocking the other half.

The welded joints of these boilers have been tested by a series of experiments upon the tensile strength of strips of plate cut out across the weld, which were taken from several boilers from the opening cut out for the steam dome R, Fig. 16. Three sets of strips were tested, of 1, 1⅞, and 1½ inch width respectively, and each 7½ inches length, cut out of the plate transversely to the weld, which was in the middle of each piece. The following was found to be the average breaking strength per square inch of these strips:—

Experiments to test strength of Welded Joints.

Width of Strips.	No. of Strips tested.	Broke in Weld.	Broke in Solid.	Breaking Strength per square inch.		
				Least.	Greatest.	Average.
Inch.				Tons.	Tons.	Tons.
1	15	8	7	16·5	23·8	20·2
1⅞	4	2	2	19·6	22·2	21·0
1½	4	1	3	18·1	23·5	21·7
Total	23	11	12	16·5	23·8	**20·6**
Also	11 Strips of the same plates *unwelded*			20·7	25·8	**23·6**

From these results it appears that more than half of the strips broke in the solid and not at the weld, and the average breaking strength

of the 23 welded plates was within 1-8th of the full strength of the 11 unwelded plates; while the worst pieces, including some cases of as extremely defective weld as are at all likely to occur in practice, had more than two thirds of the full strength of the unwelded plates.

In reference to the cost of construction of the welded boilers in comparison with the ordinary class of lap-jointed single-rivetted boilers with angle-iron ends, it has to be noted that there is an increase of weight of 1¼ ton in the new boilers, the weight of the 11 ft. boilers, 3 ft. 11 ins. diameter, being 7¾ tons as compared with 6½ tons in the old class of boilers of the same dimensions. This increase arises from the thick-edge plates, and from the hoops and joint strips, which weigh about 2¼ cwts. each; and the joints, instead of being single-rivetted, are double-rivetted on each side of the joint, making four rows of rivets.

The total cost for labour and material is £465 in the new boiler, as compared with £415 in the old class, being an increase of £50 in each new boiler. The labour alone in the new boiler is £65 as compared with £55 in the old class, being £10 increase in the new boiler. In these costs however the whole labour is taken as hand work in both cases; but from the present experience it appears that the item of labour in flanging and bending is now reduced more than one half by the use of the flanging and bending machines that have been described. In the construction of the new boilers the cost of welding, as regards labour, has averaged 7*s.* per lineal foot of joint. The cost of the welding tackle, as shown in the drawings, has been £25 to £30.

There have been nineteen of these welded boilers in constant use upon the Midland Railway for the last 6½ years, and the result has proved so thoroughly satisfactory that this construction has now been permanently adopted for the engines of this line. Up to the present time all these nineteen boilers have been examined once, and have been found in good condition; the mileage of each during the 6½ years that they have been running has been equal to about 175,000 miles, and each boiler has had one set of tubes worn out.

s yet however they show no signs of grooving even at the flanged nds, where the greatest corrosion took place in the old construction ith the angle-iron joints. Two of these boilers have been examined vice, and were also found to be in good condition at the second xamination.

Mr. W. KIRTLEY exhibited a large number of specimens of corroded lates from locomotive boilers of the ordinary construction, together vith specimens of the thick-edge plates, flanged and bent; and lso the strips of welded plate that had been broken in testing the trength of the welded joints.

Mr. W. NAYLOR thought the importance of the subject brought forwards in the paper just read was sufficiently established by the fact which had been mentioned of there having been as many as eleven explosions of locomotive boilers during the last year, due mainly to the effects of corrosion. The increase of pressure that had taken place in locomotive boilers during the last thirty-five years, from 50 lbs. to as much as 160 lbs. per square inch, had no doubt much to do with the repeated explosions that still occurred; and though he believed the high pressure of 160 lbs. had been adopted for the sake of economy in the application of the steam, he doubted whether economy was really gained by it in practice, taking into consideration the greater wear and tear of the boiler and gearing; but even if that were the case he thought that safety should be the first consideration, and economy might then follow. At present it was clear from so large a number of explosions having occurred during the past year that safety was giving way to economy; and he strongly recommended that the working pressure should be reduced from 160 lbs. to not more than 120 lbs. per square inch.

The construction of boiler described in the paper appeared to him certainly a step in the right direction, by getting rid of the strains which caused the corrosion to produce such serious effects in ordinary locomotive boilers. The defects of the present construction of locomotive boilers with rivetted lap joints, and the danger of employing a high pressure of steam with such a construction, were rendered apparent even in the testing of the boilers by hydraulic pressure, before they were put to work. For in testing boilers of 50 inches diameter in the barrel and 60 inches across the firebox, with water pressure up to 200 lbs. per square inch, the joints were found to appear sound up to about 150 or 160 lbs., but when the pressure was increased to 200 lbs. there were numerous leakages at the joints, showing that joints so made were not sound under so high a pressure. Taking the direct tensile strain upon the iron, if the plates were $\frac{1}{2}$ inch thick the tensile strain with a diameter of 60 inches and the pressure of 200 lbs. per square inch amounted to 12,000 lbs. or nearly $5\frac{1}{3}$ tons per square inch on the section of the iron; and therefore at the longitudinal lap joints there was a force of $5\frac{1}{3}$ tons per square inch acting at a leverage of $\frac{1}{2}$ inch to spring the joint open and bend the plates, while at lower pressures the strain upon the joints was proportionately less. Hence taking into account the continual variations of pressure to which locomotive boilers were subjected in working, he fully concurred in the view given in the paper, that it was the mechanical action of the strain upon the lap joints which produced the serious effects of corrosion that were observed. This was also confirmed by the experience of locomotive boilers made with butt joints instead of lap joints, as in the case mentioned in the paper of the boiler made by Messrs. Sharp Roberts and Co. in 1847 (No. 658), where there was no grooving at the butt joints; and he had lately examined a similar boiler made by Messrs. Slaughter, which showed no signs of grooving after twenty years' work. It was true these boilers had not been subjected to any excessive pressure, such as 160 lbs. per square inch; but the entire absence of furrows at the joints after that long period of working was nevertheless a satisfactory proof of the advantage of butt

joints. The longitudinal tensile strain upon the plates forming the barrel of the boiler was not nearly so great as the lateral strain, for the area of the ends was much smaller in proportion to the circumference by which the strain was borne; but with the leverage afforded by the lap joints, this amount of strain was still sufficient to produce the serious grooving that was found at the transverse circular joints of the boiler barrel, and at the angle-iron joints at the smokebox and firebox ends.

The rivetting of the joints in boilers was also a source of weakness in the construction. For with the ordinary $\frac{7}{8}$ inch rivets placed at 2 inches apart centre to centre there was only 56 per cent. of the metal left at the rivetted joints as compared with the body of the plates. At the same time the plates were to a certain extent deteriorated by the strain put upon the iron in punching the rivet holes; and he had found by experiment that the strength was as much as 10 per cent. less after punching the holes, as compared with drilling them, when there would be no strain put upon the fibre of the iron in making the rivet holes. Altogether therefore the strength at the rivetted joints could not be taken as more than about 50 per cent. of that of the solid plates, and hence it was highly important that some other mode of uniting the plates should be adopted; and he thought the welding of the longitudinal joints, as described in the paper, was decidedly a good plan, and the specimens exhibited of the welded plates that had been tested showed that the welding had been very satisfactorily accomplished. Although this was the best mode of construction that had yet been adopted, it still involved the risk of the weld being unsound, to which all welding was exposed; and he believed there would be a still further improvement effected before long, by having the several lengths of the boiler barrel rolled each complete in a solid hoop, without any longitudinal joint, in the same way that tyres were already rolled out of a solid piece of metal without any weld.

He agreed with the statement made in the paper as to the corrosion being much more serious below the water line than above; but there were also certain places above the water line in locomotive boilers, where he had observed the effects of corrosion

to be particularly marked, and these were along the top corner of the back plate of the firebox shell, and at the angle-iron joint round the base of the steam dome. In both of these places he had found a considerable grooving in several boilers that he had examined; and it would be remembered that in the case of a recent explosion of a locomotive boiler on the Metropolitan Railway it had been found that the steam dome had been blown off, which no doubt was due to corrosion having taken place round the base of the dome, the mechanical action of the bending of the plates under pressure being concentrated at that part in consequence of the hole cut out for the steam dome.

Mr. F. W. WEBB remarked that, in reference to the working pressure employed in locomotive boilers, the pressure in the locomotives on the London and North Western Railway was limited to 120 lbs. per square inch, and that had been the limit for many years past. The plan that had been long adopted on the same line for partially obviating the defects of the ordinary lap joints had been the telescopic form of boiler, in which the circumference of the successive plates was smaller towards the smokebox end of the barrel, each successive plate being put inside the preceding one, so that the strain was more nearly in the line of the plates, though not entirely so; and by this means the bending action upon the transverse circular lap joints was considerably reduced. This did not however make such a perfect job as the butt joints with outside cover plates, of which they had now had ten years' experience on the London and North Western Railway for the longitudinal joints. A great many of these boilers with butt joints had been examined, and there had not been any corrosion observed along the longitudinal joints, as the plates were not subjected to any material bending at those joints; but a considerable grooving had been found to take place at the transverse joints, opposite to the edge of the outside lap; and there was the usual deep grooving at the angle-iron joints at the smokebox and firebox ends, where the bending action still came into play.

The grooving which had been mentioned as taking place along the top corner of the back plate in the firebox shell was not owing

so much to corrosion, he thought, as to the severe bending strain thrown upon that part, whenever the firebox end of the boiler was not left perfectly free between the frames so as to allow for expansion and contraction. In the case of six engines that had been handed over to the London and North Western Railway from another line, the plates were observed to appear much corroded at this point, and became worn through after three years' longer working, and the wear could not be explained at the time; but in repairing the engines, the firebox end, which had previously been rigidly attached to the frames, was left free to slide, and after that there was no further difficulty from corrosion at this part of the boiler.

The CHAIRMAN enquired whether any trial had been made to ascertain what would be the extent of corrosion in a boiler that was not at work, leaving the boiler full of water for a length of time and using it in fact merely as a tank, and whether the corrosion would then occur at the same places where it was now found in the boilers at work.

Mr. F. W. WEBB did not know of any experiment of that sort having ever been tried; but it was not likely that any grooving at the joints would take place when the boiler was not subjected to the mechanical action from the alternation of the pressure. In the locomotive boilers on the London and North Western Railway the present practice was to form each length of the barrel out of a single plate bent round into a complete circle, so as to have only a single longitudinal joint instead of two; and this joint was then turned to the upper side of the barrel, so as to be in the steam space above the water line, whereby they had now almost entirely got rid of the difficulty of corrosion along the longitudinal joint.

The corrosion over the general surface of the plates depended a good deal, he believed, upon whether the boiler was fitted with iron tubes or brass tubes, particularly where the water employed in the boiler had any acid properties. For in the case of locomotives running upon some parts of the Yorkshire section of the London and North Western Railway where the water was of a very acid quality, he noticed that in boilers having iron tubes it was found

the general surface of the plates was not injured, on examining them when the tubes were taken out after five or six years' work; but the corresponding boilers working under the same circumstances with brass tubes were found to have the plates very badly pitted all over, which was no doubt owing to some galvanic action between the brass and iron.

The injurious effects of straining in locomotive boilers by alternate expansion and contraction were plainly shown in connection with the use of the injector for supplying the feed water to the boilers. The injector being originally placed at the side of the firebox, delivering the feed water in at that part, it was found that the constant straining of the outside firebox plate, from the continued changes of temperature owing to the intermittent stream of feed water supplied by the injector, caused the plate in a short time to become nearly cut through at the bottom close to the foundation ring of the firebox. This was partly due however to want of proper management on the part of the enginedriver in regulating the feed according to the rate of evaporation in the boiler, so that he was continually turning the injector on and off; but with proper care the injector could be so regulated as to deliver a constant stream of feed water into the boiler, in which case the firebox plate was kept at a more uniform temperature, and did not become injured by straining.

Mr. J. FERNIE remarked that, with regard to the grooving which had been mentioned of the back plate of the firebox along the top corner above the water line, he had also noticed the same occurrence in locomotive boilers which he had examined; but he believed that in every case which he had seen the grooving at this part had been the result of bad workmanship originally. The plate had either been overheated at that place in the flanging, or had not been sufficiently sound to stand the flanging, or there had been some defect in the manufacture of the boiler which would account for the grooving. He thought therefore this was altogether a different case from the grooving round the angle-iron joint at the smokebox end, where there was no doubt that the corrosion took place whether the plate was really sound in material or not.

In the testing of the strips of welded plate that were exhibited, the average breaking strain struck him as being much lower than might have been expected, considering that the thickness of metal at the weld was greater than in the body of the plate; and he had been surprised to find that so many of the strips gave way at the weld. He thought however that this might perhaps be attributed to the manner in which the strips were obtained for testing, being taken from the piece of plate cut out of the boiler across the weld to form the hole for the steam dome; and this piece of plate being bent to the circle of the boiler, it was possible that sufficient care might not have been exercised in flattening the strips before testing them, and the strength of the iron might have been injured in the straightening. He suggested that it would be well to try testing the strips in their original curved form, without flattening them; and he thought it would also be desirable to take strips of a greater width than only 1 inch, when a more satisfactory result would probably be arrived at.

Having seen the welded boilers described in the paper in all the stages of their manufacture, and having also seen them tested to a pressure as high as 200 lbs. per square inch, he had great pleasure in bearing testimony to the very capital job that was made by this mode of construction, and there was no mistake that they were first-rate boilers both in workmanship and strength; they were indeed the strongest locomotive boilers running at the present time. With regard to the proposed plan of making the rings of the boiler barrel each in a solid hoop without welding, he understood that some experiments had been already made for accomplishing this object; and he should be glad to know whether it was intended to roll the hoop in the same way that weldless tyres were rolled, or to draw it like a tube. There was not much probability he thought of the working pressure being reduced in locomotive boilers; for the great aim now upon the railways was to obtain increased engine power for drawing the increased weight of the trains and for attaining a higher speed. For these purposes increased pressure of steam was required and stronger boilers, and the boiler described in the paper was an important step in that direction.

Mr. W. NAYLOR observed that an important fact bearing upon the strength of locomotive boilers when under pressure of steam was that the tensile strength of the plates was greater at the temperature of the high pressure steam than when cold. Having had frequent occasion to test the strength of wrought iron plates and bars for the Great Indian Peninsula Railway, he had found that it was usual to wait till the iron was cold, under the impression that the test would otherwise not be a fair one; and he had accordingly tried an experiment with a piece of best Yorkshire bar iron in order to ascertain the difference of strength when the iron was exposed to about the heat of a locomotive boiler. The bar was 2 inches by 1 inch, or 2 square inches section, and was cut into three lengths; and the two end pieces being tested cold broke at 51 tons tensile strain or $25\frac{1}{2}$ tons per square inch. The centre piece was then heated red-hot, and was allowed to cool gradually until an alloy of lead and tin would only just melt upon it, showing that the temperature was about 350° Fahr. or about the temperature of 120 lbs. steam. At this temperature the bar required 61 tons or $30\frac{1}{2}$ tons per square inch to break it, showing a tensile strength 20 per cent. greater than when cold. It was also found that the heated bar did not stretch more than half as much as the cold bars before breaking.

Mr. W. S. LONGRIDGE remarked that, in respect to the proposed plan which had been referred to of making the boiler barrel solid without any weld, he had been aiming at the accomplishment of this object for some time, and was more than ever confirmed in the idea by the information which had been given in the paper regarding the improved welded boilers and their advantages in freedom from corrosion as compared with the ordinary lap-jointed boilers. The object he had in view was only to extend to boiler plates the same plan of manufacture that he had already adopted in making weldless tyres, which had been found so successful that they were becoming more and more universally used; and in a few years he was satisfied that no tyres would be used which were made with a weld. He hoped in a short time to be able to make a weldless cylinder of boiler plate up to 4 feet diameter; and though the details of the mode of manufacture were not at present

completely worked out, the intention was to build up a cylindrical coil, welded in the same way that guns were now constructed, from a double coil made of bars about 2½ inches square, having a 5 inch hole through the centre of the coil: this coil, after being forged and expanded in the usual way to 15 or 16 inches diameter of hole, to be bored and turned. The object of boring and turning was not only to ensure the soundness of the iron in the previous stages of manufacture, before the bloom was submitted to the final process of rolling, but also to allow of greater accuracy being obtained in completing the finished ring. This bloom of 16 inches inside diameter having then been subjected to a welding heat in the furnace would be taken to the rolling machine, and rolled out to 4 feet diameter. This process might be accomplished after a little experience as easily he thought for a boiler barrel as for a tyre; and though at first it was not intended to attempt rolling the hoops of a greater length than 3½ feet, he considered that when this was successfully effected it would only be a question of strength and size of machinery to roll an entire boiler barrel of 10 feet length. The experiments he was making were with iron; but had it not been for the prejudice at present met with against the use of Bessemer metal or other homogeneous metal for boilers, he would at once have adopted these for carrying out this system of boiler making, being satisfied that they would ultimately supersede iron for the purpose.

One point which had not been touched upon in the very interesting paper that had been read was the question of single-rivetted or double-rivetted joints; and as he observed that in all the specimens of corroded plates which were exhibited the lap joints were single-rivetted, while the improved boilers with butt joints had the outside covering hoops double-rivetted, he enquired whether it was considered that the single-rivetting employed with the ordinary lap joints had anything to do with the grooving of the plates at the joints, and whether it was on that account that double-rivetting had been adopted in connection with the butt joints in the improved boilers.

Mr. W. KIRTLEY replied that the double-rivetting of the butt joints in the improved welded boilers had been adopted only for the purpose of ensuring greater strength at the joints; and he did not think that the use of double-rivetting instead of single-rivetting would make any sensible difference in the extent of the grooving by the corrosion in the case of the ordinary lap-jointed boilers, as the injurious springing of the plate under pressure would be little affected.

With regard to the strips of welded plate that had been tested for trying the strength of the welded joints, the straightening of these before they were tested had been done with special care, in order that the strength might not be injured; and he thought the results might be taken as fairly representing the strength of the welds.

The CHAIRMAN moved a vote of thanks to Mr. Kirtley for his paper and the valuable specimens exhibited, which was passed.

The following paper, communicated through Mr. Walter May, was then read:—

ON AN IMPROVED CONSTRUCTION OF LOCK AND KEY.

By Mr. J. BEVERLEY FENBY, of Birmingham.

Although the varieties of Locks have been exceedingly numerous, yet so seldom has any new principle of security been introduced, that if locks are divided into two main classes—firstly those with fixed guards, and secondly those with moveable guards—a brief examination of the principles of construction involved in a few locks of each class will be sufficient for the purpose of the present paper.

The simple *fixed-guard* or *warded* lock is so utterly worthless for security, no matter what amount of good workmanship be bestowed upon it, that it demands but short notice. It was contrived with the intention of making the passage to the bolt intricate; but it will be seen at once that this intricacy does not really offer any security. The wards of a lock are circular arcs of thin metal, so arranged as to require a key of peculiar pattern to pass amongst them, the shape of the cuts in the key being a section of the wards. To make a really complicated box of wards, and to cut keys which shall accurately fit their sweep, is a matter requiring considerable manual dexterity; and some warded locks are therefore expensive. But even with the best of them all that it is necessary to do for opening the lock is to take a blank key which will properly fit the keyhole, coat it with wax, and then inserting it in the lock press it round against the wards, which will cause them to leave an accurate impression of their section on the key. The parts impressed are then cut out with small files, drills, and saws, and the occasional use of fine cross-cut chisels. The key will then pass those wards which impressed themselves upon it; and if these are the only wards it will go completely round and open the lock. If there are

also other wards in addition, not brought up flush with the first wards, the key is waxed again and pressed against them, and then further cut out, as before. This process is evidently one of absolute certainty, and the key so made is in all respects as capable of mastering the lock as the original key.

These warded locks are however easily opened with merely a piece of bent steel wire, bent into such a sweep as will reach right round the wards instead of passing amongst them, thus escaping all chance of being obstructed by them. Such an instrument is called by burglars a "twirl." In Fig. 19, Plate 30, is shown the key of an elaborately warded lock, and in Fig. 20 is shown a picklock or twirl which will open the lock belonging to this key, or any other lock having wards of about the same outside dimensions.

The fixed-guard or warded lock was the one in general use in the middle ages; but amongst the second class, or locks with *moveable guards*, is found the most ancient lock in the world, the Egyptian Lock, which is shown in Fig. 13, Plate 30. A A is the body of the lock, through which the bolt B passes. The pins C C C, working in cavities in the lock, drop into holes in the bolt when the solid end of the bolt is projected into the jamb of the door; and the lock is then locked. In order to unlock it, the key D is thrust into the cavity in the bolt, and then moved upwards so that the pins E E E upon it push up the pins C which hold the bolt fast; and by then drawing the key back the lock is unlocked. These locks are in general made of wood, and with three or four pins. Should any of the pins not be lifted high enough, the bolt is prevented from moving. This lock is represented on the bas-reliefs of the temple of Karnac; and as it is still used in modern Egypt in the same form, it is thus seen to have remained unimproved for more than four thousand years.

In the Letter Locks, the opening of the lock depends on the knowledge of some secret word or combination of figures. Their whole principle of action consists in having a series of rings or discs upon one spindle, each of which is marked with a separate

letter or figure and has a single slot on the inner edge; and these rings are separately turned round by hand, instead of being turned by the bit of a key, until the inside slots are all brought into one line, allowing the bolt then to pass. Such contrivances may however be considered more curious than useful, and the best constructions of them have been readily picked.

The next kind of lock is the Tumbler Lock, in which the bolt is moved backwards and forwards by the key as usual, but these movements cannot take place till a small lever with a stump on one side be lifted. This lever and stump form the tumbler, which is held down by a spring; and in the tail of the bolt are two notches, into one of which the stump fits when the bolt is shot, and into the other when it is withdrawn. All that is necessary to effect the picking of this lock is to lift the tumbler high enough for clearing the stump out of the notch, and then draw back the bolt. The tumbler may be lifted with one pick, and the bolt drawn back with another; but generally one pick will suffice for both purposes. As the tumbler only requires to be lifted high enough, and cannot be lifted too high, no nicety is needed in the operation of picking.

In the Barron Tumbler Lock the principle of double-action was introduced. In place of simple notches in the upper edge of the bolt-tail, a slot is cut out of the tail in the direction of the length of the bolt; and this slot is long enough to admit of the proper motion of the bolt while the stump of the tumbler is in the slot. The notches for the stump are cut out in pairs on both sides of the slot, exactly opposite to one another, and the spring of the tumbler presses the stump into the two bottom notches, while the key or pick has to lift it out. If however the stump be lifted too high, it enters the opposite top notch, and so stops the motion of the bolt. This arrangement effected an important advance in the art of security.

The next improvement was the Lever Lock properly so called, under which designation the majority of the modern locks may be classed. In lever locks the stump for preventing the withdrawal of the bolt is fixed on the bolt itself; and the levers are made with radial slots or "gatings" in them, to admit of the passage of the

stump in withdrawing the bolt. The same principle runs through all the very numerous varieties of lever locks, as regards their essential construction and action, their differences lying mainly in the addition of various ingenious contrivances for detecting attempts at picking the lock and for increasing the difficulty of access to the levers.

The principle of the lever lock is shown in Fig. 14, Plate 30. On the bolt B of the lock is fixed the stump S, a square-edged stud, which passes through a slot in each of the levers L; these are a series of plates having all the same external form and all working upon a common centre pin, and fitting in thickness the successive steps of the key, Fig. 15. A radial slot or "gating" G is cut in each lever to allow the stump S to pass when the bolt is withdrawn; and these gatings being cut in different positions in each lever, it is requisite before the bolt can be withdrawn in unlocking that all the gatings should be brought exactly under the stump, which is effected by the several steps of the key being made of the proper height to suit their respective levers.

In the actual manufacture of these locks, the key is first cut with an arbitrary division of the several heights of the steps; and each lever in succession being lifted by the key to its full extent, the gating G is then marked on the lever to correspond with the position of the stump S. On the accuracy with which the gating is cut to fit the stump depends the security of the lock from being opened either by picking or by a false key differing slightly from the original. A curved notch or "racking" R is made at the bottom of the gating, for the purpose of allowing the levers to be pressed back into their original position by the springs I when the bolt is withdrawn, as they would otherwise be retained in their raised position, and would then give by their inner edges a direct indication of the form of key required for opening the lock.

The celebrated Bramah Lock consists of a metal cylinder with a hole passing down the centre; and a number of slots are cut radiating outwards from the centre hole and running throughout the length of the cylinder. A groove is turned in the cylinder from the outside, so far as to cut a short distance into all the slots; and

into each slot a steel slide is fitted, having a notch cut in its outer edge, in such a position that when the slide is pushed in longitudinally to the proper distance the notch exactly corresponds with the groove in the cylinder. Into this groove fits an annular disc of steel, having nicks cut on its inner edge corresponding to the radial slots in the cylinder, and through these nicks the slides work freely. The annular disc is fixed securely in the external case of the lock; and the slides being held up by a spring, so that the solid part of each is in the nicks of the disc, prevent the cylinder from being turned round for unlocking the lock. In order to free the cylinder for turning, the slides must all be pushed in longitudinally to such an extent that their notches coincide exactly with the annular disc; the slides can then pass round upon the disc, allowing the cylinder to revolve and move the bolt. For pushing the several slides in to the respective depths required, a tubular key is used, having longitudinal slits cut in its end, the length of the slits corresponding inversely to the depth to which the respective slides have to be pushed. Should any one slide be pushed too far or not far enough, its notch will not coincide with the disc, and it will therefore prevent the cylinder from being turned.

The Bramah Lock was an admirable contrivance with remarkably beautiful mechanism contained in a small compass; and since its invention there have been several ingenious modifications of the same principle in different radial locks, such as the Yale Lock, in which the slides move radially instead of axially. One advantage in these radial locks is the greater difficulty in copying the keys, in comparison with the flat keys of ordinary lever locks: this difficulty however is not an insurmountable one.

A very ingenious addition was made to the action of the lever lock in Newell's American Lock, which was shown in the 1851 Exhibition and described in a paper at a former meeting of the Institution (see Proceedings Inst. M. E. June 1851, Page 16). In this lock the several steps of the key were made each of a separate piece, excepting the first and last steps which were solid as usual but had no action on the levers; and the intermediate steps were

secured in their places by a screwed pin passing through them and through the two fixed steps. After unlocking the lock, the key could be changed by altering the relative positions of the moveable steps; and the lock was so constructed that it admitted of being locked the next time with the altered key, while only that same arrangement of key would then unlock it again. This was effected by having, instead of the ordinary solid stump, a compound stump, in which was a separate piece for each lever; these component parts of the stump were lifted up with the levers in the act of locking the lock, and being held in their raised position by a paul which engaged in a rack formed in the back of each, the compound stump was thus made an exact copy of the arrangement of key used in locking. As the levers fell back on withdrawing the key, nothing but the same arrangement of the steps in the key could bring them again to correspond with the several parts of the stump for unlocking.

The important point gained in this lock was that no copy of the key was available for opening the lock, unless taken from the very arrangement of key with which the lock was last locked: the intention being that the pieces of the key should be changed immediately after locking, their position only being noted for restoring the key to the form required for opening the lock again; consequently in the interim any wax impression taken from the key would be useless. This lock, though certainly a remarkable triumph in mechanics, was necessarily very limited in its application from the great complication and costliness of its construction; although from the excellence of the workmanship it was not liable to derangement.

A further improvement of great ingenuity was subsequently added to this lock, by making the bit or acting part of the key removable, the stem or handle being unscrewed from it after the key was put into the keyhole. The turning motion was then given by a secondary handle independent of the key, and the bit of the key was carried round inside the lock to do the work, whilst the keyhole was entirely closed during this time by a revolving plate. Although this accomplished the closing of the keyhole whilst the right key was in action, and thereby greatly increased the difficulty of

applying picklocks, yet the keyhole was still left open at other times for the action of picklocks; and the use of a key requiring to be unscrewed and screwed together again every time that the lock was either locked or unlocked involved a serious practical objection.

Though locks such as those already referred to exhibit great dissimilarity of construction, yet there is one point in which they all agree, and that is in the possession of a direct passage from the outside to the works. Although various locks have been devised with the object of having no direct passage to the works from the outside, one consideration shows the inevitable existence of such a passage: namely that without it the key could not possibly at one and the same time touch the hand of the operator and the works of the lock. It therefore follows that any instrument which can pass in the same space as the key may be brought to bear on the works, whatever may be their construction.

It can now be shown that, if picking instruments are thus brought to bear on the works through the keyhole, there is a regular tentative system whereby the picking of any lock with an open keyhole can sooner or later be effected. The mode of operation is in its chief features the same for all moveable-guard locks. Taking as a single example the Egyptian lock shown in Fig. 13, to pick this lock the following method is used. A piece of wood or metal is taken similar to the key D, but without the pins E; and wax or clay having been spread on the upper surface, it is put into the lock and pressed up against the holes C, so as to take an impression of their position. Corresponding pins are now fixed in these places, and the key so made is again introduced into the lock; and by the exercise of just so much skill as is required to lift the pins C free from the bolt, without lifting the key so far as to cause its own pins to catch in the upper case A, the lock is picked. The pins on the key may then be regulated to the proper height, so as to make it impossible to lift up too high with them; and when this is done the counterfeit key is in all respects as good as the one properly belonging to the lock. If the pins put on the counterfeit

key for the purpose of picking the lock be made of some substance having sufficient tenacity to lift the lock pins and draw the bolt, but not strong enough to resist the shearing action between the bolt B and the case A, then however high the lock pins C may be lifted by the counterfeit the bolt will yet be withdrawn, and the precise length of the pins on the key will at the same time be obtained.

The picking of this elementary moveable-guard lock comprises the principles of the art of lock-picking; and to apply these principles to the picking of a lever lock, the following variation of the process is put in practice. Reverting to the lever lock shown in Fig. 14, if by any means except the use of the key the gatings G can be brought into such a position as to allow the stump S to pass through them, that constitutes picking the lock. This has been performed with the simple tool shown in Figs. 16, 17, and 18, which consists of a tube F made to fit upon the drill pin of the lock; and on this tube fits another external tube H, which turns and slides easily on the inner tube F, but with perfect steadiness. Each tube has a projecting step at the extreme end, corresponding to a certain extent with the steps of the key, the difference lying only in the length. With the step on the inner tube F the bolt B, Fig. 14, is pressed back so as to feel the stump S against the levers L, and a constant pressure is kept upon them by the stump by means of the weight W, Fig. 16, suspended from an arm on the inner tube F. Meanwhile the levers are one by one carefully felt and manipulated by the step on the outer tube H, each lever being slightly lifted in succession according as it is found to be held by the pressure of the stump, until all the levers are at last got free from that pressure by the open gating G in each lever being brought exactly under the stump, which is then free to pass down the gatings; and the back step F of the picking tool, which is continually pressing upon the bolt by the weight W, is then able to unlock it without obstruction. The false notches or teeth on the face of the arcs in the levers, Fig. 14, are intended to frustrate this plan of bringing a pressure to bear on the bolt while raising the levers; but although they add very considerably to the difficulty of picking the lock, they by no means

actually prevent it; for locks with sixteen levers having false notches as well as other improvements have been picked.

This was the mode of picking so successfully shown by Mr. Hobbs, who at the time of the 1851 Exhibition opened in this manner a lever lock of one of the best makes. A similar method has been used with locks made on the Bramah principle, only that in this case the radial slides have to be pushed in, while a slight twist of the cylinder, to make the slides bind against the guard-plate, supplies the place of the pressure put upon the bolt of the lever lock; and in this way a Bramah lock was also picked by Mr. Hobbs. In the radial locks the only variation is in pushing the slides radially instead of axially, the cylinder being slightly twisted at the time as in the Bramah lock; and a lock with as many as 40 radial slides has been picked. There are also additional modes of operation in lock-picking, such as smoking the working parts with a taper, so that the right key when used shall indicate the gradations of its action on the works, which are afterwards examined by a small mirror introduced through the keyhole. Enough has however been stated to show that there is nothing to prevent attempts at picking from being made on any lock having an open keyhole, nor any certain means of ascertaining whether at any time such attempts are in progress.

The other mode of attacking a lock is by taking an impression of the true key and making a counterfeit key from it. As a remarkable instance of this method may be named the case in which two of the best lever locks were opened a few years ago by Agar and his confederates, and £12,000 worth of gold was stolen, weighing upwards of 200 lbs., while in transit on the South Eastern Railway from London to Paris. In this important robbery, which took place on 15th May, 1855, the gold was sent in three boxes, iron-bound and sealed, and packed in a bullion safe, which was secured by two new locks of the best and most improved make, duplicate keys being kept at the London and Folkestone stations. By the collusion of two of the railway officials wax impressions of the keys for the two locks were obtained, and counterfeit keys made from them; but it was found requisite to make no less than seven trials

of these counterfeit keys before they could be sufficiently perfected to open the locks. The only means of making these trials was by travelling with the bullion safe in the van, by collusion of the guard of the train, at the same time running the risk in each trial of creating a fatal suspicion by over-lifting the detectors in the locks. The whole was however ultimately accomplished with complete success, and the robbery effected, although only after a period of several months' perseverance, to which the thieves were stimulated by the very large amount of the prize to be obtained.

From the foregoing observations it is evident that there are two important defects in the principle of the previous lever locks, which being defects in principle are fatal to their security: namely the means of access to the works of the lock through the keyhole, allowing of a series of attempts being made to open the lock by picking instruments; and also the facility afforded for repeating the trial of a false key made from a wax impression of the true key, and thus perfecting it by successive alterations after trial. In consequence of the possibility thus allowed of making these successive attempts either by picking instruments or by a false key, it has been shown by the cases that have occurred of locks of the best makes which have been falsely opened, that, however numerous and complicated may be the secondary impediments introduced into these locks, there can be no real security against the ultimate success of sufficiently numerous and persevering attempts, except by the adoption of some new principle of construction specially meeting the above two defects.

In the invention of the Improved Lock and Key now to be described, the writer's object has been to meet this requirement. In Fig. 1, Plate 25, is shown an elevation of this lock, such as is made for an iron safe: two of the front cover plates being removed to show the construction.

The head B of the main bolt is of such a thickness as to be flush with the face of the levers L and guard A; and the strap or tail D of the bolt is thin, and passes behind the levers and guard and also behind the plate H H. The part of the tail D which would

lie under the levers L and cylinder C is removed, as seen in Fig. 6, Plate 27, and replaced by a separate flat plate or stump-bolt, carrying the stump S. This stump-bolt has a projection K upon it, let into a recess in the tail D of the main bolt, but with $\frac{1}{10}$th inch vertical play in the recess. A spring in the tail of the main bolt presses the stump-bolt downwards, keeping the stump S in the notches of the levers L, as shown in Fig. 1. The stump-bolt can thus descend $\frac{1}{10}$th inch at first without moving the main bolt, and this amount of vertical movement is sufficient to carry the stump in and out of the notches in the levers; but the stump-bolt cannot descend further without taking the main bolt with it.

Immediately in front of the bolts comes the fixed plate H H, in which is cut the cam groove shown by the dotted line J J; and also the vertical slot E for the pin P to work through, together with another vertical slot in which the stump S fits and works. This plate carries the centre pin U on which the levers L turn. The levers are six in number, though any other number may be used; and they occupy collectively 3-8ths inch thickness. In front of the plate H is fixed the guard A, which is made of iron or steel, and has the brass cylinder C ground into it. The guard is made a shade thicker than the levers L, in order to prevent the back plate H and the corresponding front plate from being so tightened on the levers as to impede their freedom of movement. The cylinder C is the same thickness as the levers, excepting the centre boss F, which projects from the back of the cylinder and works in a bearing in the back plate H, and also projects in front through the thickness of the two front cover plates. The small keyhole in the centre of the boss goes only a short distance into the cylinder C, being merely for the purpose of enabling the stem of the key M, Fig. 8, to turn the cylinder; the bit of the key is a separate piece N, which is inserted through a separate keyhole into the radial slot of the revolving cylinder C, as shown at N in Fig. 1.

This radial slot is cut in the side of the cylinder C that is furthest from the levers when the cylinder is in the position shown in Fig. 1; and in the slot fits the slide block R, which is a steel block having a pin projecting on each side. The back pin enters

the guide groove J J in the back plate H, as shown by the dotted line, and the front pin enters the corresponding guide groove in the front cover plate which is shown removed. The back pin of the slide block projects through the back plate H, as shown in Fig. 7, and works in the cam groove O in the tail of the stump-bolt S, Fig. 6, which is so shaped that as the slide block travels round the guide groove J J, shown by the dotted lines, it moves the stump-bolt vertically as may be required according to the position of the bolts and levers.

In the position of the lock shown in Fig. 1, the bit N has been inserted into the vacant space of the radial slot in the cylinder C, in front of the slide block R. The size of this vacant space is 3-8ths inch long by 1-8th inch wide and 3-8ths inch deep; and in the two front cover plates of the lock, and also in the door to which the lock is attached, a hole is made of the same shape. In the door there is no bearing for the centre boss F, but only a small keyhole corresponding in size with that in the boss F for inserting the stem of the key.

In the position of the parts shown in Fig. 1, it will be seen that the levers L are held pressing down against the circumference of the cylinder C by their springs I bearing against the pin P. In this position also the bolt spring between the main bolt and the stump-bolt, Fig. 6, presses the stump S down into the notches of the levers, so that the levers are completely locked by the stump, as seen in Fig. 1.

In order to unlock the lock, which in Fig. 1 is shown with the bolt shot, it is necessary that all the gatings G in the levers should be brought precisely under the stump S. Through the centre keyhole F there is no communication possible at any time with the levers L; nor will any instrument, however slender, if passed into the radial slot through the aperture at N be able to reach them, whether the cylinder C be in the position shown in Fig. 1 or turned round into any other position. For the only difference made by turning the solid cylinder C is that the radial slot in it is carried away from the aperture in the external plates, and the solid part of

the cylinder is brought opposite to the aperture, which is thereby completely closed against the insertion of a picking instrument. This construction accordingly not only precludes the possibility of opening this lock with an ordinary key, in which the part that acts on the levers is attached to the stem of the key, but it also renders it an absolute impossibility to introduce a pick of any form, as nothing can reach the levers L except a detached piece of such a size and shape as to be capable of travelling round in the vacant space left in front of the slide block R in the radial slot of the cylinder C.

For the purpose of unlocking the lock the bit N, Fig. 9, is used. This bit is of such a size as to fit into the vacant space of $\frac{3}{8} \times \frac{3}{8} \times \frac{1}{8}$ inch in the radial slot of the cylinder C; and the indent at V is merely for the purpose of ensuring the insertion of the bit in the right direction, the external aperture for the bit being made with a corresponding projection to fit the indent in the bit. This bit being inserted through the aperture in the door is pushed in by means of the key stem M, which is flattened on two sides for that purpose, as shown in Fig. 8; and the bit is thus pushed home into its place in the radial slot of the cylinder, as shown at N, Fig. 1.

The key stem M is now inserted into the centre keyhole F, and the cylinder is turned round by it in the direction shown by the arrow, carrying round the slide block R and the bit N. The slide block R while moving through the concentric portion at the commencement of the guide grooves J J does not affect the bit; but by means of the cam groove O in the tail of the stump-bolt, Fig. 6, it moves that bolt so far as to lift the stump S completely out of the notches in the levers L, which are thereby left free to be raised. On continuing to turn the cylinder C the eccentric part of the guide grooves J J causes the slide block R to move outwards along the radial slot, pushing the bit N before it; and the bit is thus made to project beyond the circumference of the cylinder, which it can then do, being no longer confined by the guard A. The further projection of the bit as the cylinder revolves causes the steps in the bit to lift their respective levers; and the steps in the bit are so arranged that, when the cylinder arrives at the position

shown in Fig. 2, all the gatings G are brought simultaneously opposite the stump S, which is instantly shot down through the distance of the $\frac{1}{10}$th inch play by the bolt spring. The bit N remains in contact with the extreme part T of the levers while the stump S is entering the gatings, the action of the bolt spring being so rapid that the bit cannot move through any appreciable distance during the time.

In other locks a spring action of this kind would greatly facilitate the picking, inasmuch as it would afford the gentle uniform pressure desired upon the levers, which is given by the weighted arm F in the picklock previously described, Fig. 18. In other locks therefore the bolt is caused to move and the stump to enter the gatings by the direct contact of the key with the bolt, instead of by a spring; but as the key, while moving the stump into the gatings, is also altering its position under the levers, a slight tremulous motion of the levers is thereby occasioned, which no care in manufacture can obviate. This tremulous motion is aggravated by the circumstance that, as the keyhole is open to inspection, it is necessary to make all the levers fit flush with one another when down, in order to avoid affording any clue to the shape of the key from the positions of the levers; but as the various steps of the key, being of different lengths, describe different arcs, the curves of the levers when raised are of necessity in error to them all. The result of these combined faults is that the gatings have to be made wider than the stump, to allow a sufficient amount of play, thus introducing a fatal element of insecurity in the construction of the lock, since the security is of course enhanced in proportion as the gatings fit the stump accurately. In the new lock on the contrary the arc T, Fig. 2, in each lever can be shaped truly to its own proper radius, independent of all the rest of the levers; and as the action of the stump is instantaneous in catching the gatings as soon as they are all brought simultaneously under it, the stump and gatings can be made to fit one another with the most perfect accuracy, and without the slightest play.

On turning the cylinder C further round, the bit N passes from under the levers, which remain held back by the insertion of the stump in the gatings; and just before reaching the position shown

in Fig. 3, Plate 26, the slide block R has pushed the bit completely out of the radial slot, and the bit falls down as shown in Fig. 3, and drops through a hole into the inside of the safe that is locked. At this point the back pin of the slide block comes in contact with the lower side of the cam groove O in the stump-bolt, Fig. 6; and by turning the cylinder C onwards to the position shown in Fig. 5, the withdrawal of the bolt B is completed, bringing the parts into the position shown in Fig. 5. In these drawings only one lever L is shown; but there are altogether six levers, as shown in the sectional plan, Fig. 7. The pin P is fixed in the tail D of the main bolt, so as to travel with the bolt; and by this means the springs I are released from strain, as shown in Fig. 5, as soon as the bolt is withdrawn.

From the nicety with which the various parts of this lock are constructed, it is evident that the levers must be very accurately lifted by the bit of the key in order to withdraw the bolt; and therefore any error in the bit, such as would occur with a false bit, will effectually prevent the lock from being opened. This may be illustrated by supposing the false bit to be so close an imitation as to have five of its steps absolutely correct, and the sixth only slightly wrong: though it is almost impossible that such a near approach to correctness could be attained in practice. The counterfeit bit being inserted in the lock and the cylinder turned round, all will go on the same as with the true bit, up to the time when the false bit reaches the point T of the levers, as previously shown with the true bit in Fig. 2. Here a change of action takes place; but what is the nature of the change the operator has no means as yet of ascertaining. In the case supposed, where five of the steps in the bit are right but the sixth is wrong, the gating of the sixth lever does not precisely coincide with the others nor with the stump S; and the consequence is that, at the critical moment when the stump ought to spring into the gatings and hold back the levers from falling forwards, it will be prevented from entering the gatings, owing to the entrance being partly blocked up by the one lever which stands more or less across it.

The fact however that the stump cannot enter the gatings does not become known to the operator until the cylinder C has been turned further round so as to bring the slide-block pin in contact with the lower side of the cam groove O in the stump-bolt; and before this point has been reached the false bit has already passed clear of the levers, which not being retained by the stump are instantly thrown forwards again by their springs, and locked in their original position by the stump entering the notches. At the same time the false bit has dropped into the inside of the safe in the same manner as the true bit, as shown in Fig. 4.

Hence a person putting a false bit into one of these locks will not only infallibly lose it at the very first trial, but will do so without gaining any information as to the nature of its inaccuracy; for as the gatings of the levers cannot be seen or felt, all that can be told about the action of a false bit is that it has failed to open the lock. In fact a counterfeit bit passes under the levers and through the lock just like the true bit; and it is only the stoppage afterwards met with of the bolt that indicates the failure of the false bit, which is by that time gone beyond recovery. Whatever amount of labour therefore may have been spent on the fabrication of a counterfeit bit, this bit can only be tried once, so that no alteration can afterwards be made in it.

Nothing that can be inserted into the radial slot of the cylinder C through the aperture in the front plates can do any injury to the lock; and a charge of gunpowder inserted in that way would only blow out again at the orifice without damaging the lock, both the apertures for the key being merely blind holes with parallel sides.

For the manufacture of the bits for the keys of this lock a self-acting machine is employed, in which the height and width of the several steps in the bit are regulated by adjustments of very great accuracy and admitting of an almost endless variety of figure for the bits. This key-cutting machine is shown in Figs. 10 to 12, Plates 28 and 29, and consists of a small circular saw A running vertically, of the same thickness as each step in the bit I, which is brought up

to the saw by the slide-rest B. The bit I is fixed in the holder C, which rocks upon a centre, so as to give the required curvature to the edge of each step in the bit when cut by the saw, as shown in the full-size section of the bit-holder, Fig. 11. The adjustment of the depth of cut is effected by the set screw D upon the slide-rest coming up against the eccentric ring E upon the bed of the slide-rest; this ring is turned round by hand, and set to sixteen different positions by means of the catch-pin F and the sixteen holes on the circumference of the ring, allowing of sixteen different depths of cut. The lateral adjustment for the pitch between the successive steps of the bit is effected by the two bed-screws G G acting on the slide-rest B, having a dividing plate on the head and such a pitch of thread that one turn of the screws traverses the slide-rest through the exact distance of one step in the bit. The occurrence of any play or backlash is entirely prevented by having the screws placed one at each end of the slide-rest; so that by slacking back one screw through one or more turns and then advancing the other through the same number of turns, the slide-rest is always held with perfect steadiness between them, filling exactly the space between the ends of the two screws.

The number of changes admissible in this key-cutting machine, if used for making keys for locks having six levers, is the number of permutations that sixteen terms are capable of when taken six together, which is upwards of sixteen millions. Some of these changes are so slight that too great accuracy of workmanship would be required to make the locks accordingly; but of those changes that differ from one another so far that no lock could be opened by any other than its own key, more remain than could be used up by all the locks in the world.

The writer may observe that it was the study of the circumstances of the great gold robbery previously referred to, and of the various modes of picking locks, which led him to turn his attention to the achievement of what had been so long and perseveringly sought after, namely an unpickable lock. The principle of a detached bit has been previously tried, in so far as that locks have been made in which the bit of the key was deposited in the lock by unscrewing

the key stem, and then withdrawn by screwing in the stem again. But inasmuch as the detached bit, even though it failed to open the lock in the case of a counterfeit key, could always be brought back again to the keyhole and removed, this admitted of a repetition of attempts with successive alterations of the one counterfeit key, without the certainty that any warning would be given by the lock of such attempts having been made.

In another still more complicated lock with a detached bit there were two keyholes, into one of which the bit of the key was put, and the stem being then unscrewed from the bit was put into the second keyhole and turned round so as to close the first keyhole over the bit; a separate handle was then turned to work the lock, six separate operations being required for either opening or closing the lock. Further a kind of retainer has been attempted by so arranging the lock that, if any key was put in but the right one, it was held in the keyhole in such a manner that it could never be got out. In this case however, if the false key would not open the lock, neither would it let even the right one do so, and it would be necessary to break open the door secured by the lock.

In the new lock described in the present paper the special points that have been aimed at are the following:—

Firstly, in no position of the lock is there any access to the works from the outside through the keyhole. This access through the keyhole is more or less a defect in all other principles of lock, as it admits of feeling and manipulating the works for the purpose of getting information for picking the lock in the absence of the right key; whereas in the new lock there is no opening whatever at any time, except the two plain parallel recesses into which the key and the bit are fitted. From the moment the turning of the lock commences both these recesses are effectually blocked up: the one for the bit being conveyed bodily away from the keyhole, and its place taken by the solid metal of the cylinder; while the other is completely filled by the key, which cannot be withdrawn except by turning it back to the original position. In consequence of this construction no injury can be done to the lock by explosion of

gunpowder in the keyhole, the only openings from the outside being parallel at their sides, and not communicating with any portion of the interior of the lock; and the simplicity and solidity of construction are such that the revolving cylinder is made practically air-tight within its bearing. This effectually prevents all attempts to open the lock by picklocks, and leaves no alternative but the attempt to make a sufficiently accurate copy of the true key.

Secondly, as no clue whatever can be obtained from the outside of the lock respecting the key required, the attempts upon the lock are thus limited to the chance of obtaining a wax impression of the true key. The difficulty of making a counterfeit key sufficiently correct by this means for opening one of the best of the previous constructions of lock is very great; but in the new lock this difficulty is greatly increased by the fact of the levers remaining absolutely stationary while the stump enters the gatings, in consequence of which the gatings are made so close a fit to the stump that an exceedingly minute error in the lifting of any of the levers is sufficient to prevent the lock being opened. This extreme delicacy of construction can be carried out practically without objection in the new lock, because there is no possibility of putting a strain from the key upon the stump, so as to cause injury by forcing it at the moment of entering the gatings; for the only force acting upon the stump at that time is the uniform pressure of its own spring. In addition to this source of increased safety, there is the still more important circumstance that only a single trial can be made of each counterfeit bit; because, if carried forwards far enough to try its effect in opening the lock by passing the levers, the bit is inevitably lost by falling through the lock and inside the door. Thus not only is all chance prevented of a second trial with the same key, but the bit retained inside the door gives warning of the attempt having been made, and shows how near the counterfeit key has approached to the original. The numerous cases that have occurred of attempts to open locks by counterfeit keys, such as the remarkable instance previously referred to, show that even with the most practised hands it is next

to impossible to make from a wax impression a key that will serve for opening a good lock the very first time it is tried; and the striking importance is therefore seen of this arrangement in the new lock, which prevents more than a single attempt being made with a counterfeit.

Thirdly, another advantage to be named in this lock is that the stem alone of the key is required to lock it, but it can only be unlocked by the complete key. The stem therefore can be left by the principal of an establishment for locking up by a subordinate; but the bit, which is the essential part of the key required for opening the lock, need never be used or seen by any one but the principal himself. As the hole in the external door-plate for the stem of the key has a notch on one side only to admit the key-stem, and the cylinder is prevented from making a complete revolution, the stem of the key cannot be withdrawn from the lock except when the bolt is shot; so that its absence from the keyhole serves as a proof that the bolt is shot.

Fourthly, one other advantage in this lock is its simplicity and solidity of construction. It contains no more parts than the simpler forms of lever lock having the same number of levers, and the total number of separate pieces in the complete lock is only sixteen. The principle of security therefore upon which the new lock is constructed avoids entirely the complications and the delicate and minute class of work rendered necessary in other locks by the use of detectors and the other auxiliary contrivances employed for increasing the difficulty of picking.

Mr. FENBY exhibited specimens of the new lock, and showed its action both with the true key and with counterfeit keys; and he showed by trial that the counterfeit failed to open the lock, notwithstanding that by means of the permutating cutting machine it had been made a much nearer approach to a perfect copy than

was practicable in the best handwork from a wax impression. He also exhibited the key-cutting machine, employed for cutting the bits; and also a set of burglar's tools employed for drilling into the door of an iron safe sufficiently for breaking open or removing the lock, showing that the hold required for giving the cutting pressure upon the powerful drill employed for the purpose was obtained by a steel cross piece inserted into the keyhole and turned at right angles, so as to hold across inside the lock; but in the new lock, as the keyhole had no opening into the lock and only a slight shoulder on one side, no means were afforded for obtaining the required hold for the drill.

A specimen was also exhibited, lent by Messrs. Hobbs and Co., of one of the permutating locks, similar in construction to the one shown at the former meeting of the Institution (see Proceedings Inst. M. E. 1851, Plates 33 to 35), having the key composed of a number of separate bits, the arrangement of which upon the key stem could be varied at pleasure, while the lock could only be unlocked with the particular arrangement by which it had been locked. The present lock had also in addition the subsequent improvement referred to in the paper, the stem of the key being removed from the bits during the operation of locking and unlocking.

The CHAIRMAN remarked that the paper just read gave a very excellent and clear description of the detailed working of the new lock, and he thought this construction of lock was a most valuable one, as affording real security against all fraudulent attempts. He enquired whether there would be any possibility of tampering with the lock by examining it upon the inside of a safe door, whenever the door might happen to be left unlocked.

Mr. FENBY replied that there was no means of tampering with the lock from the inside of the door, as the two keyholes for working the lock were only in the front face of the door, and the lock was all closed up on the inside of the door, excepting the hole through which the bit was allowed to drop out; but this would be useless for the purpose of tampering with the lock, as the bit dropped down a tube leading to the bottom of the door, through which no examination of the lock could be successfully made.

The CHAIRMAN enquired whether there was any provision against the bit being accidentally locked up inside the safe, in which case it appeared the lock could not be opened again.

Mr. FENBY replied that the owner of the safe must of course be careful after unlocking the safe to take the bit out before locking it again, otherwise there would be no means of opening the lock afterwards with that key. As a precaution however against any such accident each lock was provided with three bits, all duplicates, one of which would be kept in the pocket for use, while the two others would be preserved in a place of safety for the chance of any such contingency. Moreover in most of the safes fitted with these locks, the tube through which the bit dropped had been made of such a length as to carry out the bit on opening the door, dropping it into a small tin tray outside the safe; and by this means the accidental locking in of the right bit was rendered impossible. One of the advantages of the new lock was that the stem of the key was not required to be kept constantly in the possession of the owner, but it might be left in the lock, as the bit alone was the valuable part of the key; and as the bits were of such small size and convenient shape, a number of them might readily be kept in the pocket by a person having charge of a number of safes, without the inconvenience attending a large bunch of ordinary keys. In the case of an attempt being made to open the lock with a counterfeit bit, the advantages of retaining the counterfeit inside the safe were not merely that the person attempting the lock was deprived of his instrument, while the proprietor immediately discovered the attempt upon the next occasion of opening the safe; but the retention of the counterfeit itself afforded the means of judging, by a comparison with the true bit, whether the attempt had been made altogether in the dark as to the actual construction of the lock, or whether it was likely that some clue regarding the true bit had been obtained by means of a wax impression or otherwise. In the latter case the owner of the safe might think it desirable to have the lock taken off, and the arrangement of the levers altered, and a new bit made, so as to baffle any further attempts.

Mr. W. S. LONGRIDGE observed that the inconvenience that had been alluded to with the new lock, of accidentally locking up the bit inside the safe, was no greater than occurred with an ordinary safe lock if ever the key was accidentally lost; in either case, unless the precaution was taken of keeping a duplicate in reserve, it would of course be necessary to have the safe broken open.

The CHAIRMAN enquired how the ideas had been arrived at of separating the bit from the key, and of preventing all access to the works through the keyhole, and also of retaining the bit inside the door after any attempt at unlocking.

Mr. FENBY replied that his attention had in the first instance been attracted to the subject of the picking of locks as a mechanical problem, and he had found that there had hitherto been no principle in lockmaking which could effectually baffle persevering attempts at picking. For although there were certain complicated constructions of locks, having many points of excellence, they had all yielded in time to the picking instrument in clever hands; and it must be remembered that any individual lock when once constructed remained stationary as regarded subsequent improvement, whereas the art of picking that lock was continually progressing towards success, with all previous constructions of locks, and it was clear therefore that the lock must ultimately be defeated. He had been further stimulated in the investigation of this subject by the occurrence of the great gold robbery referred to in the paper; and the circumstance which had struck him most forcibly in connection with that robbery had been that locks of the best make hitherto known had admitted of seven successive trials being made upon them without detection, each trial furnishing the information for further perfecting the counterfeit key, until the locks were at length opened.

These considerations had led him to the conclusion that two points were established and were required to be kept in view for the construction of any lock that should be really secure against fraudulent attempts. The first point was that wherever a man could get instruments into the lock he could ultimately solve any problem laid before him by the maker of the lock, as the lock when

once made could be tried any number of times if an instrument could be got into it at all. Hence he had concluded that it was requisite for all access to the interior to be cut off, so as to preclude all possibility of getting a picklock in; and this was accordingly accomplished by adopting the plan of separating the bit from the stem of the key. The second point established was that it was necessary to prevent the possibility of making a succession of trials with the same counterfeit key; and it had then struck him that, if the bit of the key were arranged to drop inside the safe in unlocking, there would be no means of going on gradually improving and touching up the counterfeit from the results of previous trials, as the false bit would be irrecoverably lost in the very first attempt, without furnishing any clue whatever as a guide for alteration in a subsequent trial. The first lock that he had invented for meeting the requirements thus pointed out had been made with a solid block having a tunnel through it, but involving the same principle of retaining the bit of the key and keeping the levers inaccessible from the outside. Subsequently however he had abandoned that construction and produced the new lock shown in the drawings, having the revolving barrel with radial slot.

The CHAIRMAN proposed a vote of thanks to Mr. Fenby for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

31 JULY AND 1 AUGUST, 1866.

The ANNUAL MEETING of the Members was held in the Lecture Theatre, Mechanics' Institution, David Street, Manchester, on Tuesday, 31st July, 1866; JOSEPH WHITWORTH, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

WILLIAM ADAMS,	London.
GEORGE ARMSTRONG,	Wolverhampton.
WILLIAM CARPMAEL, JUN.,	London.
HENRY CHAPMAN,	Paris.
EDWARD FREER DANIEL,	Shrewsbury.
JOSEPH BEVERLEY FENBY,	Birmingham.
CHARLES JOHN GALLOWAY,	Manchester.
WILLIAM IRELAND,	Manchester.
ALBAN MEREDITH,	Dalton-in-Furness.
ALFRED SACRE,	Sheffield.
JOSEPH SMETHURST,	Guide Bridge.
ELI SPENCER,	Oldham.
JOHN CLASSON STEPHENS,	Dublin.
JOHN STEVENSON,	Middlesbrough.
HENRY WREN,	Manchester.

ASSOCIATE.

Richard Lewis White, . . .	Swindon.

GRADUATES.

James Butler, ...	Manchester.
Thomas Snowden Butler, . .	Leeds.

The following paper was then read:—

ON THE PROOF OF GUNS BY MEASUREMENT, WITH DESCRIPTION OF THE INSTRUMENT EMPLOYED.

By the President, JOSEPH WHITWORTH, Esq.

Many rifled Guns have doubtless been permanently injured by having been proved with excessive charges. The writer's object has been to ascertain what amount of charge any particular description of gun will bear, without a permanent alteration of its parts; and by the use of his Contact Measuring Instrument for this purpose a difference of one ten-thousandth part of an inch can be detected.

Before commencing the proof an exact measure is taken of the bore of the gun opposite the centre of the powder charge A, Fig. 1, Plate 31; and also opposite the centre of the projectile B. A shot is then fired with a powder charge somewhat smaller than that intended when using the proper weight of projectile. The bore is again measured at the same places, and also near the base of the shot, which will be found to have enlarged the most; and this enlargement takes place more or less even with what may be considered a legitimate charge, and is altogether independent of the general overstraining and enlargement produced by an excessive charge.

As a general rule the writer has found that, as regards accuracy of fire and penetration, the best length for a solid projectile is three diameters; and the total weight of powder that the gun can wholly consume before the shot has left the gun is about one seventh of the weight of this projectile. Applying these proportions to the 600 pounder gun now in our service, which has a bore of 13 inches, it should fire a 990 lbs. shot and consume 141 lbs. of powder; while the American gun of 15 inches bore should fire a 1522 lbs. shot with 217 lbs. of powder. It thus appears that

the bores are too large in the above cases; and therefore the guns themselves will be found totally inefficient when they have to contend with others of smaller bores using the proportions of powder and shot that have been named.

The Instrument designed by the writer for the proof of guns by measurement is shown in Figs. 4 to 6, Plates 32 and 33. Fig. 1 is a longitudinal section of a 7 inch gun, the dotted lines showing the measuring instrument as when placed in the bore for measuring. Fig. 4 is a longitudinal section to a larger scale, and Fig. 6 a transverse section of the gun and the head of the measuring instrument drawn half full size, showing the three sliding feelers and contact pieces by which the measurement is effected.

The long stem of the measuring instrument is composed of two tubes, which for strength and lightness are made of steel. The outer tube C is attached to a brass head, which has three radial arms DDD. Into grooves in these arms are accurately fitted the three sliding steel feelers F, which are secured in their places by a covering plate. The inner ends of these feelers work in three inclined dovetailed grooves in the wedge piece G, which is attached to the end of the inner tube E; their outer ends, which come in contact with the sides of the bore of the gun, have pieces of hardened steel screwed on in order to reduce the wear to a minimum, and render the feeling more sensitive. To the outer end of the inner tube E is attached a square-threaded screw H, Figs. 4 and 5, 1-10th inch pitch; and to the same end of the outer tube C is attached a brass nut J working on the screw H. This nut is made in two pieces which are tightened together endways on the screw, so as to take out back-lash or "lost time." On the nut is fitted a micrometer wheel K having fifty divisions. A slot is cut in the outer tube C, and a pointer I attached to the inner tube works through this slot and affords the means of measuring accurately the movement of the inner tube.

As the nut J attached to the outer tube is fixed, the inner tube is drawn in or out 1-10th inch by each revolution of the micrometer wheel; and as the inclined grooves in the wedge piece G have an

inclination of 1 in 20, one division of the micrometer wheel K causes the feelers F to move out or in through ·0001 inch or 1-10,000th inch; and an enlargement of the bore to this minute extent of 1-10,000th inch is decidedly felt by moving the rod and feelers backwards and forwards a short distance within the bore of the gun. The rod C is supported at the muzzle of the gun on a grooved brass pulley L, Fig. 4, which facilitates its free movement backwards and forwards in the bore of the gun. In order to measure with the greatest accuracy, it is necessary that the bore of the gun be carefully washed out after each discharge, as any fouling or particles of grit left in the bore would interfere with the requisite measurement. With care a skilful manipulation may always detect a difference of only one ten-thousandth part of an inch.

During the competitive trials of the special committee at Shoeburyness in 1864 the writer designed this measuring instrument for ascertaining for his own information the alteration which took place in the bore of the 70 pounder gun under trial. The measurements, which were carefully taken at different times during the firing of nearly 3000 rounds, showed that the enlargements of the bore with successive charges of 10 lbs. of powder and 70 lbs. shot were regular, and were due entirely to wear of the gun in the powder chamber; but when the powder charge was increased, and a large air space left, the gun being loaded each time with a number of shot, the enlargement of the bore was so rapid that a continuance of those charges must have led to the destruction of the gun, as the enlargements showed that a permanent set must have taken place at every discharge.

In the first 2886 rounds the total enlargement in diameter at the base of the shot was ·0198 inch, as shown in the accompanying Table. In the next 50 rounds, 40 were fired with heavier shot, namely 20 rounds with 140 lbs. and 20 with 280 lbs., and an air space of 12 inches was left between the powder and shot; the further enlargement of the bore at the base of the shot was ·0170 inch, showing that nearly as much total enlargement was caused by these 50 rounds as by the previous 2886 rounds. The

last 15 rounds, fired with still heavier shot varying from 350 to 490 lbs., and 5 of them with an increased powder charge of 15 lbs., produced a still further enlargement of ·0157 inch, being nearly equal to that of the 2886 or the 50 rounds.

The total enlargement of the bore at 35 inches in from the muzzle after firing 2886 rounds was ·0018 inch.

Trials of 70 pounder Whitworth Gun.

Weight of Powder.	Weight of Shot.	Air Space.	No. of Rounds.	Enlargement of Bore.
Lbs.	Lbs.	Inches.		Inch.
10	70	—	992	·0062
10	70	—	1036	·0054
10	70	—	858	·0082
		Total	**2886**	**·0198**
10	70	12	10	
10	140	12	20	
10	280	12	20	
		Total	**50**	**·0170**
10	490	12	10	
15	350	6	1	
15	420	6	1	
15	490	6	3	
		Total	**15**	**·0157**

These trials show that, so long as the strain did not exceed the elastic limit of the material, no enlargement of the bore beyond that due to wear took place; but when this limit was exceeded, a certain amount of permanent injury was done to the gun by each discharge.

The use of this measuring instrument simply affords the means of carrying out in the testing of guns the principle that is adopted in testing girders, in which the effect caused by the test loads is carefully observed as to the permanent set produced, and any risk of injury from undue strain is thus avoided.

Mr. W. FAIRBAIRN observed that the measuring instrument which had been described appeared well adapted for the purpose intended, and afforded the means of measuring with extreme accuracy the exact enlargement produced in the bore by a number of discharges. The use of the measuring instrument in the trials described in the paper now showed that nearly as much damage was done to the gun by enlargement of the bore in 50 rounds with a very heavy charge as in 2886 rounds with the more moderate charge that the gun was intended to carry; and it therefore appeared, particularly in the case of the heavier charges, that it was merely a question of time how long the gun would stand the repeated discharges before becoming so much damaged as to be in danger of bursting. The result thus arrived at by applying the system of measurement to the proof of guns was a confirmation of what was observed in other cases in connection with the strains of materials; for in regard to the limit of elasticity in different materials, although this was intended to mean such a limit of strain that any lower strain would not produce a permanent set in the material, yet he had found that a strain amounting to only one tenth of that limit, when repeated often enough, led ultimately to fracture; and he therefore inferred that, even in the case of still smaller charges, the gun must ultimately be destroyed by repeated discharges, even supposing it should stand as many as 6000 rounds with only the same amount of enlargement that was now found to be produced in 3000 rounds. The great importance however of employing measurement in proving any description of ordnance was evident, in order to have reliable means of determining how many rounds a gun should sustain before it became dangerous and absolutely likely to burst.

The PRESIDENT remarked that one point which had been satisfactorily established by the use of the measuring instrument was that the wear of the gun was mainly confined to the powder chamber, and that very little wear was produced by the friction of the shot in the gun. It had been anticipated by some military and naval men that iron shot would never do at all for an iron gun, but that they would wear the gun out in much less than 1000 rounds.

The measurement showed however that, after firing as many as 3000 rounds with the iron shot, the total wear at a distance of 35 inches from the muzzle amounted to only about 1-500th inch on the diameter, or only 1-1000th inch on each side of the bore, which was a very satisfactory result to arrive at.

Mr. B. FOTHERGILL enquired whether it was a cylindrical or spherical shot which produced so little wear in the bore of the gun.

The PRESIDENT explained that the shot was not cylindrical or spherical, but was hexagonal with the corners rounded, fitting the bore of the gun, as shown in the drawing (Figs. 2 and 3, Plate 31), which exhibited the most perfect form of shot for length of range and accuracy of flight; the length of the shot was about three diameters, and the rifling was about one turn in twenty diameters length. The ordinary shot was of cast iron; and it was rounded off at the front end, and tapered a little at the rear, as shown in the drawing (Fig. 2).

Mr. R. NAPIER enquired whether the wear produced by the shot was greater on the lower or the upper side of the bore.

The PRESIDENT replied that the wear of the gun took place upon the flat sides of the hexagonal bore, and there would not be any difference in the wear of the bore on one side more than on another with the polygonal form of rifling.

Mr. F. J. BRAMWELL enquired what was the amount of windage allowed in the gun, and whether the wear from the rush of gas was not found to be principally on the upper side of the bore. He asked also what length the powder would occupy in the gun, when the weight of powder employed was one seventh that of the shot, according to the proportion given in the paper.

The PRESIDENT replied that the amount of windage in the gun was 5-100ths inch in diameter; and the tendency of the polygonal shot was to centre itself in the bore when started. The windage of ·05 inch was obtained by allowing ·02 inch difference between the diameter of the bore and of the shot, and also by an additional windage being given at each of the corners of the hexagonal bore by bevelling outwards each of the sides or "flats" from the centre to

the corners; this additional windage at the junction of the flats and corners was ·015 inch on each side or ·03 inch in diameter, making a total windage at the corners of ·05 inch in diameter between the bore and the shot.

The 10 lbs. weight of powder employed with the 70 lbs. shot occupied a length of about three diameters in the bore of the gun, the space occupied by the shot and the powder being the same when the proportion of 7 to 1 in weight was adopted, which had been found by experiment to give the best results. In the longitudinal section of the 7 inch gun shown in the drawing (Fig. 1, Plate 31) the powder filled the space A of about 20 inches length, and the shot B occupied also a length of 20 inches. He considered it desirable to put as much powder into the gun as could be wholly consumed before the shot had passed out at the muzzle, and then it was clear that the greatest possible effect was obtained from both the gun and the powder; and in accordance with this condition he had found that as a general rule three diameters length of powder was the best for a solid shot such as he had employed, having a length of about three times its diameter.

Mr. F. J. BRAMWELL noticed that in the second and third sets of trials with the 70 pounder gun an air space had been left between the powder and the shot, which he presumed had been done for the purpose of increasing the strain on the gun; and he enquired whether a longer air space than the 12 inches left in the trials would still further increase the strain, or whether there was a limit in the increase of strain resulting from the air space.

In reference to the enlargement of only 1-50th inch in the bore after the first 2886 rounds, he enquired whether this small amount of enlargement might not be merely the permanent set resulting from taking up the slack parts of the gun, and not a sign of injury produced by overstraining; and he asked what was considered the proportion of enlargement that must take place with an ordinary charge, without indicating injury to the gun.

The PRESIDENT replied that the air space left between the end of the powder and the shot in the trials was expressly for the purpose of "punishing" or intentionally overstraining the gun, in order to

try the effect of an extreme strain; but in ordinary practice no air space was left, the shot being always rammed home on the powder. With reference to the amount of the air space, some experiments which he had made with rifle barrels showed that the longer the air space the greater was the strain on the gun; and showed also how very severe a strain was produced on a gun by leaving any length of air space at all. The mode in which the strain acted upon the barrel was also very remarkable, the effect appearing to be concentrated at a particular point, producing a definite annular bulge all round the barrel at that point, instead of the enlargement being distributed uniformly over the length of the air space. In a rifle barrel of ·45 inch diameter with a special charge of 120 grains of powder and a special hexagonal shot weighing 700 grains, an air space of 3 inches length being left between the powder and the shot, the bulge was found at $\frac{1}{4}$ inch in front of the point where the back end of the shot had been before firing; and by then lengthening the air space 1 inch, a second bulge was obtained 1 inch in front of the first bulge. This result appeared very striking, the interval between the two bulges being perfectly parallel and well defined in position.

In reference to the question whether the gun might not receive a certain amount of enlargement at first in the way of permanent set, without sustaining any damage, he did not think that this was the case. It should be mentioned indeed that a certain amount of wear took place in the powder chamber, not from strain but from the action of the gas rushing past at the moment of firing; and the greatest amount of this wear was a little beyond the base of the shot: not exactly at the base of the shot, in a gun of the kind shown in the drawing, but from 1 to 2 inches in front of that point, over the shot itself. With the exception however of the wear occasioned at that particular place by the rush of the gas, he thought that the gun was injured by any enlargement at all, however small the amount. In experimenting at Woolwich three weeks ago with a 150 pounder gun of similar construction to the one shown in the drawing, he had tried a charge of 20 lbs. of powder, which was about the utmost that the gun could consume. After firing a single

shot of 150 lbs. weight, no enlargement whatever was found to have been produced, and two shots were then fired with the same result; but on firing three shots, an enlargement of about 1-1500th inch was found to have been occasioned at three places near the breech. This showed that the gun would fire two shots without injury, but with three shots it was so far damaged.

Mr. J. KENNAN enquired whether the three shots were put in close to one another, or whether any air space was left between them.

The PRESIDENT replied that no air space was left between the three shots, and they were flat-ended and all in contact, so that they would have the same effect in the gun as if all one shot.

Mr. H. MAUDSLAY asked whether any difference in friction had been found between cast iron shot and wrought iron shot.

The PRESIDENT said he was not able to state whether there was any difference or not, as wrought iron shot was so seldom used, cast iron being almost exclusively employed for the purpose. The small amount of wear produced in the bore of the gun by the friction of the shot might be explained by the circumstance that there was always a certain amount of fouling in the gun from the previous discharge, so that the shot rode upon a coating of fouling every time the gun was fired. There was found to be a little wear just at the muzzle of the gun, in consequence of the shot not being always put in quite straight in loading the gun.

Mr. W. FAIRBAIRN said he had had the pleasure of visiting the President's works on the previous day, and had seen there a very ingenious vent designed by the President for obviating the objection hitherto met with in guns of the vent becoming worn away after repeated discharges so as to require frequent renewal. It consisted of a piece of platinum in the form of a long plug, screwed into the breech of the gun and having the vent hole drilled through its centre, while the inner end of the plug was enlarged into a conical head; and from the results of experiments such an angle of cone had been obtained that neither the wear from the escape through the vent at the moment of discharge nor the pressure of the discharge produced any effect upon the size of the aperture

in the platinum, in consequence of which a much larger number of rounds could now be fired before the vent piece required renewal.

Mr. R. NAPIER enquired what was the angle of the cone in the platinum vent piece.

The PRESIDENT replied that the inclination that was found the best for the sides of the cone to the axis was about 30°, as shown at T T in the full size longitudinal section of the platinum vent piece (Fig. 8, Plate 33). With a more obtuse cone it had been found that the aperture of the vent became gradually enlarged by the wear caused by the rush of gas through the vent hole; while with a smaller angle than 30° the vent aperture became gradually contracted in size, owing to the platinum cone being driven in by the pressure of the explosion; but with the particular angle of cone that was adopted this gradual contraction just compensated for the wear of the vent, so as to maintain a constant size of aperture. Previously guns required to be vented by means of a fresh tube at about every 400 rounds; but with the platinum vent as many as 4000 rounds had been fired with one vent piece, the only wear being on the flat surface of the end that was exposed to the inside of the powder chamber.

Mr. W. FAIRBAIRN moved a vote of thanks to the President for his very interesting paper, which was passed.

The following paper was then read:—

DESCRIPTION OF AN IMPROVED REVERSING ROLLING MILL.

By Mr. JOHN RAMSBOTTOM, of Crewe.

The improved Reversing Rolling Mill described in the present paper has been in operation for seven months at the Steel Works of the London and North Western Railway at Crewe, having been designed and laid down by the writer. The special point in the arrangement is that the rolls are driven direct by the engine, without the intervention of a flywheel; and the engine and rolls together are reversed each time that a heat is passed through, the rolling being alternately in opposite directions. The idea of reversing a train of rolls by reversing the engine at each passage of the heat through the rolls was first suggested by Mr. Nasmyth, but has never to the writer's knowledge been carried out before.

A general plan of the rolling mill and engines is shown in Fig. 1, Plate 34, and an enlarged plan of the Engines in Fig. 2, Plate 35; Fig. 3, Plate 36, is a side elevation of the engines, and Fig. 4 a transverse section. They are a pair of direct-acting horizontal engines coupled at right angles, as shown in the plan, Fig. 2; and they are reversed, without shutting off steam, by hydraulic power, by means of the arrangement shown in plan in Fig. 2 and in elevation to a larger scale in Fig. 7, Plate 37. The reversing shaft A is connected by links to a piston working in a small cylinder B of 4 inches diameter and 10½ inches stroke, the water pressure being 300 lbs. per square inch. The admission of the water to the cylinder is regulated by a slide-valve worked by the shaft and hand lever CC. This shaft is prolonged and carried outside the engine house, as shown in the plan Fig. 2, in order to place the attendant in a position where he may be able more

easily to seize the right moment for reversing. The shaft C is made hollow, as shown enlarged in Fig. 6; and through it runs a second shaft with hand lever DD, which regulates the main steam-valve E of the engines by the lever and connecting rod F. By this means the attendant standing outside the engine house at G and in full view of the rolls has complete command over the engines by the two handles C and D. A hand lever is also fixed on the reversing shaft A, as a provision for reversing the engines in the event of any accident occurring to the hydraulic gear or any deficiency in the water supply.

The engines make $3\frac{1}{4}$ revolutions for one revolution of the rolls, and the speed of piston is about 4 times (4·14) that of the circumference of the rolls. The cylinders H H, Fig. 2, are 28 inches diameter with 4 feet stroke. The expansion link K, Fig. 3, shown to a larger scale in Fig. 5, is the straight link devised by Mr. Alexander Allan, and is driven by three eccentrics and rods, two at one end and one at the other, so as to avoid the oblique thrust inevitable with only two eccentric rods.

The connection between the engines and the mill train is made, first by means of an ordinary clutch shown at JJ in Figs. 1 and 2, and secondly by a friction coupling designed by the writer, and shown in position at LL. This friction coupling is shown enlarged in Figs. 11 and 12, Plate 40. The disc M is keyed on the driver shaft N, and a smaller disc O is mounted wobbler-fashion on the mill shaft P, and tightly compressed between the driver disc and a loose ring I bolted to the driver disc. Annular segments of alder wood packing $\frac{3}{4}$ inch thick are interposed between the discs to increase the bite, and are placed so that the fibres run radially to the shaft. This friction coupling is capable of transmitting the whole power of the engines in regular work; but if from a sudden obstruction the motion of the rolls is arrested, the driver disc slips round the follower without moving it, and no injury is sustained by any part of the machinery. In ordinary roll trains it has sometimes happened that the "breaking spindle" has broken, and that the broken end has acted as a lever to shift the engines from their bed; but by the present arrangement the probability of such

an occurrence is very much diminished, and many stoppages and breakages are avoided, whereby loss of capital is prevented.

The engines are of such power that there is no necessity to do more than just start them before the heat enters the rolls. Thus the heavy flywheel usually employed is not required, and consequently the engines are easily reversed; neither is there any expenditure of steam except at the very time of rolling. For the same reason the wear and tear of machinery and the necessary lubrication are reduced to a minimum in this mode of driving the rolls. Instead of the heavy flywheel employed in the ordinary arrangement of rolling mills as a reservoir of power, in which the power of the engine is previously accumulated ready to be concentrated upon the work at the time of rolling, the boiler is made to serve as the reservoir of power in the new rolling mill; and it has this great advantage, that whereas the flywheel contains only a limited store of power, which continues diminishing during the time of application, the boiler supply is practically unlimited, so that the rolling power continues constant throughout the time of operation.

In the rolling of puddled slabs for the frame plates of locomotive engines, which are reduced $3\frac{1}{2}$ inches in thickness at one heat in the rolls, about twenty-one reversals of the rolls are required. These are effected with great ease and almost instantaneously by the arrangement above described, the shock being transmitted to the elastic cushion of steam in the cylinders of the engines. This handiness allows of either iron or steel plates being passed through both the roughing-down rolls and the finishing rolls at one heat; and the work is thus done with a minimum expenditure of heat and waste of metal. It has been found on trial not at all difficult to reverse the engines together with the whole train of rolls as many as 73 times in one minute.

There are two pairs of Rolls, one for roughing down and the other for finishing. The roughing-down pair are 24 inches diameter by 6 feet length; they are shown in elevation and plan in Figs. 8 and 9, Plates 38 and 39, and Fig. 10, Plate 40, is an end elevation;

Figs. 13 and 14, Plate 41, are transverse sections through the housing and through the rolls.

In these rolls a new description of tightening-down gear has been designed, in order to obtain greater facility and accuracy in tightening down the rolls, and to ensure the top roll being at all times perfectly parallel to the bottom roll. This gear is shown in Figs. 8, 9, and 14. It consists of a vertical wrought-iron shaft Q, carried by a cast-iron bed-plate and supported at the upper end by the wrought-iron standard S, between the housings, and in the centre of the length of the rolls. On the top of the shaft is keyed a spur wheel T, which drives the two spur wheels UU on the vertical holding-down screws of the top roll R. These screws work in steel nuts let into the housings, as shown in Fig. 13, and the top bearing of the centre shaft Q is also a corresponding screw working in a brass nut, so that the centre spur wheel T rises and descends simultaneously with the two outer spur wheels UU when the gear is in motion. A vertical hydraulic ram V, Figs. 8 and 10, is placed in a convenient position near the rolls; and a chain, shown by the thick dotted line, is fastened at one end to the barrel of the ram, carried thence over the pulley on the ram head V, down again to the fixed pulley below, and thence round a guide pulley X on the nearer roll housing to the spiral chain-barrel upon the lower end of the vertical centre shaft Q. The chain makes a few coils round the barrel, and the end is fastened to the barrel near the top. Another chain is fastened to the barrel near the bottom, and after a few coils round the barrel quits it in nearly the same horizontal plane as the first chain, and passes off on the opposite side and over a guide pulley on the further housing; a weight W is suspended at the end of this chain, heavy enough to overhaul the other chain and slack back the tightening-down screws of the top roll, when the water pressure is shut off from the hydraulic ram V.

When a slab has entered and passed once through the rolls, the engines are reversed, and the water valve being opened the ram V rises and hauls in the chain, driving the chain barrel and causing the tightening-down screws UU to descend and lower both ends of the top roll simultaneously to the required extent. This process is

repeated after each passage of the slab through the rolls. When the rolling is completed, the water is released from the ram, and the ram falls, while the counterbalance weight W on the second chain winds up the tightening-down screws to their original position; and the usual counterbalance apparatus Y, Figs. 8 and 13, applied to the top roll R, causes it to rise with the upper chocks.

The head V of the hydraulic ram, Figs. 8 and 10, carries an index finger, which by means of graduations on the guides enables the attendant to give with accuracy the requisite amount of lowering of the top roll at each reversal, and thereby to reduce each slab with certainty to exactly the same thickness. As an additional precaution in rolling a set of slabs all to the same thickness, a chalk mark is made on one of the spur wheels U, after the final rolling of the first slab; and at the final rolling of each successive slab of the same set a stop is placed in the teeth of the spur wheel at this mark, stopping the screwing down always at the same point, and thus preventing the possibility of any mistake in the finished thickness of any slabs of that set. The total vertical motion given to the roll by the hydraulic ram is $3\frac{1}{2}$ inches, while the stroke of the ram is 6 feet $2\frac{1}{2}$ inches; consequently the movement of the ram is 21 times that of the roll, and the indication by which the tightening of the rolls is measured being thus magnified 21 times gives great accuracy in the adjustment.

By this system of gearing the two tightening-down screws together by means of the intermediate spur wheel, the top roll is made to move always truly parallel to the lower roll, and there is no possibility of one end of the roll descending more than the other. Thus the two surfaces of the slabs rolled are made perfectly parallel to each other, with a uniform thickness throughout the entire width of the slab.

In the finishing rolls the same tightening-down gear is employed. These rolls are of cast iron chilled on the circumference, 24 inches diameter by 7 feet length; and they differ in no important respect from the roughing-down rolls. As the finishing rolls require only a small vertical motion, no counterbalancing gear is applied to the top roll as in the previous pair, the bottom chocks of the top roll

being supported by the ordinary transverse spring beams passed through the housings.

In order to facilitate the introduction of large slabs into the roughing-down rolls, a set of bent levers ZZ, Figs. 8 and 14, shown to a larger scale in Fig. 15, Plate 42, are attached to a horizontal shaft B running along the ground parallel to the rolls; and by means of a hand lever H on the shaft all these levers are simultaneously brought up under the slab, and by a slight movement the slab is then lifted into the rolls. Each of the levers is attached to the shaft B by an arm and pin joint, so that it can yield to any inequality on the surface of the slab; and it is brought up again by the overhanging counterbalance ball A.

From the fact that the train of rolls driven in this manner is only in motion while the heat is being passed through, it is not found necessary to use a stream of water for lubricating the roll bearings in the ordinary manner; but all the journals are truly fitted in the bearings, and are lubricated with oil and tallow.

The PRESIDENT enquired what was the greatest length of bar that had been rolled in the new rolling mill.

Mr. RAMSBOTTOM replied that the greatest length they had rolled at present was only plates 17½ feet long; but any length that was desired, from the least to the greatest, could be rolled with equal facility by simply keeping the steam on long enough, the only limit being the amount of furnace accommodation available for heating the bloom, and the extent of shop room for rolling in. The chief feature in the new arrangement was the ease and rapidity with which the rolls could be reversed at full speed, allowing of the work being rolled down rapidly, by avoiding the cooling from the delay of passing the iron back over the top roll.

Mr. R. NAPIER asked whether any break-downs or accidents had occurred since the mill was first started.

Mr. RAMSBOTTOM replied that they had had no accidents of any sort during the seven months that the mill had now been at work.

Mr. W. FAIRBAIRN enquired whether the rolling mill was employed for rolling down ingots of steel; and whether the same plan would not be applicable for rolling armour plates.

Mr. RAMSBOTTOM said he had not used the mill for rolling down steel ingots, but it was employed chiefly in rolling the frame plates for locomotives. For armour plates he thought the reversing mill would be very suitable, and the only question was one of gearing and power for rolling any size of armour plate that might be required. He had had no difficulty at present in rolling anything that had been put into the mill. On one occasion he had rolled a circular steel saw-plate, 7 feet diameter, which was of course rolled in a single piece. It had been objected to the plan of keeping the rolls parallel, by gearing the tightening-down screws together, that the plates sometimes wanted humouring, by tightening the top roll down more at one side than the other, which could not be done when the screws were geared together; but in practice the utmost extent of the humouring required was so slight that he had found it was only necessary to pass the plate through nearer to one side or the other, as the rolls themselves were not turned truly cylindrical, but slightly larger in diameter in the centre to compensate for the springing under the strain in rolling.

Mr. R. NAPIER remarked that the levers employed for entering a slab into the rolls looked very light, and he enquired whether they were found strong enough for the purpose.

Mr. RAMSBOTTOM replied that the levers were made of pieces of ordinary spring steel $\frac{1}{2}$ inch thick and $3\frac{1}{2}$ inches broad, and there were four of them on each side of the rolls, and though light in appearance they completely answered the purpose of lifting the slabs into the rolls; and with this arrangement one man at the hand lever could do more than four or five men by the old plan of running a truck at the slab to force it into the rolls.

Mr. B. Fothergill remarked that in ordinary ironworks where there were a number of furnaces in connection with the same set of rolls, the heats to be rolled would be of different thicknesses, so that it would be necessary to lower the rolls immediately from a bar or slab of say 3 inches thickness to a plate only 1 inch or $\frac{3}{4}$ inch thick; and he enquired how quickly the tightening-down gear could be altered in the new rolling mill, for changing the gauge of the rolls to suit such requirements, and whether this was done as quickly as in the usual mode by hand.

Mr. Ramsbottom replied that the top roll in the new rolling mill had a motion of $3\frac{1}{2}$ inches, and from the full width of opening it could be brought down in a few moments through the whole range of $3\frac{1}{2}$ inches by means of the hydraulic tightening-down gear, nor had any inconvenience or delay been experienced from this cause. The alteration was effected quite as quickly as with the ordinary tightening-down screws worked by hand and independent of each other; and the adjustment was made with much greater accuracy by the hydraulic apparatus, the $3\frac{1}{2}$ inches range of motion of the top roll being magnified 21 times on the scale of the hydraulic ram, which was constructed according to the arrangement of Sir Wm. Armstrong's hydraulic cranes. The range of the top roll could be further increased if desired, by altering the proportion of the gearing.

Mr. S. Lloyd observed that the old plan of reversing the rolls had never come into general use, because the process of reversing had been so slow, that, except in heavy work, it had been found quicker to pass a plate or bar back over the top roll and re-enter it than to reverse the rolls. From the description given in the paper of the new rolling mill however, it appeared that the reversing was now done so quickly and so easily that the rolls could be reversed quicker than the plate or bar could be passed over the top roll, even when working at a considerable speed. He enquired whether with very short pieces of metal the rolls were always reversed, instead of passing the work back over the top roll.

Mr. H. Maudslay observed that the case appeared similar to that of the planing machine, in which it was desirable to reverse the

tool half round for cutting during the return stroke, when the length of travel was anything considerable; but with a very short travel this was of less consequence, and the return motion might be made without cutting.

Mr. RAMSBOTTOM replied that one of the best illustrations of the facility of reversing the rolls was the mode adopted for rolling down the crop ends of plates into small sheets 1-16th inch thick, to be used as covers for the moulds in casting the Bessemer steel ingots. The men were left to themselves as to the mode of working, and they preferred to reverse the rolls for these small pieces of metal instead of passing the work over the top roll, as they found they could get on much quicker by reversing.

Mr. F. J. BRAMWELL remarked that as the engine drove the rolls direct in the new mill, without the use of a heavy flywheel, the engine itself must be of greater power, and he asked for some information respecting the comparative cost; he thought it probable the saving effected by avoiding the expense of the heavy flywheel would compensate for the cost of the larger engine.

Mr. RAMSBOTTOM considered the engine working direct on the rolls to be certainly more economical in first cost than the ordinary plan of using a flywheel. In the present instance the engine employed was larger than was actually needed, having been put down originally for driving the tyre mill, and it had afterwards been applied to the rolling mill for the purpose of testing the plan of reversing, because it was not possible to reverse with a flywheel. In putting down a new rolling mill for the same class of work, it would not be necessary to have so large an engine as that shown in the drawings. It was of course requisite to have a second cylinder working at right angles, when the flywheel was dispensed with; but even with a flywheel two cylinders were not unfrequently employed.

Mr. R. NAPIER enquired whether the work was done with less expenditure of steam by dispensing with the flywheel.

Mr. RAMSBOTTOM had no doubt that the expenditure of steam was not greater than with a flywheel, and there was certainly less wear and tear, and a great saving in time. The flywheel involved the

defect in principle of going twice over the ground, the speed being first increased by gearing from the engine to the flywheel, and then reduced again by gearing from the flywheel to the rolls; and that process necessarily occasioned a waste of power by friction, which was saved by the present plan of dispensing with the flywheel.

Mr. E. T. BELLHOUSE thought the new reversing rolling mill presented a very important practical embodiment of the great principle advocated by Mr. Nasmyth, of applying steam power direct to the work required to be done. In former years mechanical engineers had laboured under great disadvantages, owing to the want of machinery sufficiently accurate and fine for accomplishing properly the desired work. Hence it arose that, in forging, the principle of the common hammer had been made use of, and the hammer itself had been made of very great weight and driven by a powerful engine with very heavy flywheel, in order to perform the work by the aid of momentum. Subsequently these cumbrous engines and massive flywheels were superseded by Mr. Nasmyth by the direct application of the steam to the work, in the steam hammer of his invention; by which the power could be applied with the utmost nicety, exactly in proportion to the work to be done. The same important principle had since then been followed up in many other instances, and was now carried out in the new rolling mill that had been described, in which the stopping and reversing of the rolls and their adjustment for rolling to different thicknesses were effected with the greatest readiness and precision, by means of well designed mechanism; this could not however have been successfully accomplished formerly, in the absence of the facilities that were possessed at the present day in materials and manufacture. In thus dispensing with the cumbrous machinery required for obtaining the momentum that was necessary to go through the work by accumulation of force, and applying the power direct to the work in the exact proportion of the work itself, one practical result obtained was an important saving in the item of foundations, which had been a very heavy expense attendant upon the former ponderous machinery. He suggested that the same principle of driving independent sets of machinery by independent engines of

comparatively small size, each working direct upon its own machines, might perhaps be advantageously carried out in the case of cotton mills and similar manufactures, instead of the present plan of driving the whole of the machinery in the works by a single engine of very large size; the principle had been already adopted in print works and warehouses, as well as in many engineering works.

Mr. J. FERNIE said he had recently seen the reversing rolling mill in operation at Crewe, and could fully bear out all that had been stated in regard to the very efficient way in which it worked; but in existing ironworks it generally happened that an engine had been put down for more purposes than one, and then this reversing arrangement would not be applicable. At the works with which he was connected the tyre mill and plate mill were both driven by the same engine, so that reversing by the plan adopted at Crewe was not practicable. He should like to enquire whether in making common iron the plates would stand this mode of rolling, and whether the reversing would not injure the fibre.

Mr. W. M. SPARROW thought there must be a severe concussion between the teeth of the two spur wheels gearing the engine to the mill, whenever the rolls were reversed while running at any considerable speed; and he enquired what had been the experience in respect to the wear of the wheels.

Mr. RAMSBOTTOM replied that he had not experienced any drawback from the wear of the gearing, as the parts which moved quickly were all so light, and there was no large mass in motion such as a heavy flywheel, and only the action of the elastic steam to check and reverse the motion. The power being brought to bear upon the work just as wanted, and direct from the engine, there was no accumulated force to be checked in reversing, and no more force was called into play than was actually required for accomplishing the rolling. The reversing was thus effected with no more trouble or wear than in the ordinary reversing of a locomotive engine.

With regard to rolling the plates in both directions in the reversing rolling mill, he had heard it objected by steel makers that steel would be deteriorated in quality by being rolled both ways; but having himself tested the steel that had been rolled both ways,

he had found no difference in quality between that and the steel rolled only one way.

Mr. W FAIRBAIRN considered it was immaterial in the manufacture of iron or steel whether the metal was rolled first in one direction and then in the other or rolled continuously in one direction only. The only effect of the rolling, as regarded the quality of the material, was that, supposing it to be a crystallised substance in the first instance, the crystals were elongated and formed into fibres by rolling. He had had an opportunity of seeing the new rolling mill at work a few days previously, and had certainly never seen any machinery better adapted for the purpose in view. With a flywheel of 40 or 50 tons weight, reversing would have been impracticable, because it could not have been stopped in time without destroying the machinery; but by getting rid of all that enormous mass in motion the rolls could now be reversed with the greatest facility. The reversing mill was an important move in the right direction, establishing a new method in the manufacture of both iron and steel, in consequence of which he had no doubt that they would be manufactured at a much lower cost than heretofore.

Mr. RAMSBOTTOM observed that one source of saving would be that the work was got over more rapidly in the reversing rolling mill. With regard to the principle introduced by Mr. Nasmyth of applying steam direct to the work to be performed, as in the present instance, it might be remarked that this principle was gradually becoming more extensively adopted, and it was already the practice in many forges to drive the different trains of machinery by separate engines, so that the operations of one mill might not be interfered with by those of another.

Mr. W. PERRY remarked that, in regard to the plan described in the paper of gearing together the two tightening-down screws of the top roll, a difficulty was often experienced in getting the plates rolled square on the edges and of regular thickness throughout the whole width when the two screws were connected together, on account of the iron happening to be more heated along one side than the other. Moreover if a slab had been wasted at a corner in the furnace, and the top roll was always kept parallel to the bottom roll, as in

the new rolling mill, there would be considerable waste in shearing the plate square; but if the tightening-down screws were under independent control, they could be so managed as to bring up the wasted portion in rolling, so that the plate would not be wasted in shearing afterwards. On these accounts he thought it was preferable to have the tightening-down screws independent of each other, instead of gearing them together.

Mr. RAMSBOTTOM said no difficulty such as was referred to had been experienced with the tightening-down screws geared together. In rolling plates it was customary to pass the bloom through sideways in the first instance, which made it uniform in thickness throughout its entire breadth, so that any waste in the furnace would be corrected by this process; and it was then turned round and finished for length. The rolls not being made quite parallel, but rather larger in diameter at the middle, any minor errors were met by going a little nearer to one end or the other of the rolls; and if more serious errors were ever occasioned by irregular heating in the furnace, he thought there should be a change in the management of the furnace, rather than working the tightening-down screws separately.

Mr. W. YULE said he had had many years' experience in working rolls in which the tightening-down screws were geared together, and he had never met with any difficulty arising from that plan.

Mr. H. MAUDSLAY observed that in rolling angle iron or bar iron in an ordinary rolling mill, where the rolls ran constantly in the same direction, it was the practice to turn the iron over in passing it back over the top roll, so that the scale might be well knocked off before entering it again between the rolls. But in passing a heat backwards and forwards alternately through the reversing rolls, the scale would remain where it was on the iron; and he enquired whether the old plan would not have an advantage in this respect, by allowing of the iron being turned over and cleared from scale between each passage through the rolls.

Mr. RAMSBOTTOM replied that they had not as yet rolled any angle iron in the reversing rolling mill; but in rolling plates no difference was found between one side of a plate and the other,

as regarded scale. The large plates were not turned over during rolling, but the scale fell away freely from the lower side, and was always brushed off from the upper side with a broom between each passage through the rolls.

The PRESIDENT thought the improvements described in the paper that had been read were well worthy of being generally adopted in rolling mills; and he moved a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special free train, by the kindness of the London and North Western Railway Company, to Crewe, to visit the Steel Works of the London and North Western Railway, where they were shown by Mr. Ramsbottom the manufacture of steel by the Bessemer process, and the manufacture of steel tyres; and also the operation of rolling plates in the reversing rolling mill described at the meeting.

The Adjourned Meeting of the Members was held in the Lecture Theatre, Mechanics' Institution, David Street, Manchester, on Wednesday, 1st August, 1866; JOSEPH WHITWORTH, Esq., President, in the Chair.

The following paper, by Mr. Edward B. Marten, of Stourbridge, Engineer of the Midland Steam Boiler Association, was read:—

ON STEAM BOILER EXPLOSIONS AND THEIR RECORDS, AND ON INSPECTION AS A MEANS OF PREVENTION.

By Mr. EDWARD B. MARTEN, of Stourbridge.

The subject of Steam Boiler Explosions, which was brought before this Institution in June 1848 in a paper by the late Mr. William Smith of Dudley in reference to an explosion near that place, and again in 1859 in a paper by Mr. Longridge on the economy and durability of stationary boilers, is one of great importance and is now attracting increased attention. The first public notice of the subject was by a parliamentary committee in 1817, which was appointed in consequence of a very fatal boiler explosion in London in 1815; evidence was then collected as to steamboats, and many boiler explosions were referred to. That committee recommended among other things that boilers should be made of wrought iron, instead of cast iron or copper, which had been the materials mainly used previously; that they should be inspected and tested; and that there should be two safety valves, each loaded to one third of the test pressure, under penalties for any excess. A great part of the information now existing upon the subject, especially in regard to the earlier explosions, is to be found in the records of inquests after fatal cases; and some of the careful reports of eminent engineers on those occasions have materially assisted in the formation of correct views as to the causes of explosion. Latterly also the printed reports of the inspectors of mines, and more especially the reports of the explosions of locomotives illustrated by diagrams by the inspectors of railways, have furnished very valuable information. Since the subject has been taken up by private associations for the prevention of explosions, many more records have been published, although their usefulness is much impaired by their not containing the names of the places whereby the explosions could be identified.

When the writer's attention was first directed to this subject, he met with great difficulty in obtaining correct records of boiler explosions, from which to arrive at the results of past experience; and wishing to base his own opinion on facts, rather than on the inferences of others however reliable, he followed the example of the Franklin Institute in their elaborate investigation of the subject, and collected all the records he could find; and by way of facilitating reference, arranged an index, a manuscript copy of which is presented with the present paper to the Library of this Institution. All must be agreed as to the importance of reliable information on such accidents as boiler explosions; and the writer would suggest that this Institution may materially aid in obtaining the desired records and placing them within easy access, by becoming the depository of reports on explosions, and by inducing those who have the opportunity to forward copies of reports, that these may be arranged so as to be easily found and consulted. It is very desirable that these reports should as far as possible be illustrated by sketches, as aids to the description; and also by slight models like those now shown to the meeting, by which the whole matter may be seen at a glance. So few persons comparatively have the opportunity of examining boilers after explosion, that the most erroneous ideas have prevailed, and theories have been advanced which would soon be dissipated by practical experience or by reading accurate reports. It would also very much aid in the understanding of published matter on the subject, if full descriptions of each case alluded to in illustration could be obtained. These records are as useful to the engineer as the "precedents" or "cases" to the lawyer or the surgeon. After any serious explosion the newspapers of the neighbourhood in which it has occurred contain voluminous articles describing the disastrous result and the damage done, which, although useful as far as they go, do not in the least assist in arriving at the cause of explosion. The really important particulars, such as the description and construction of the boiler, its dimensions, and the pressure at which it worked, are in most cases omitted altogether.

The record of explosions presented to the Institution contains a list of the boiler explosions in each year of the present century, as far as known to the writer, with the names of the places, and the description and sizes of the boilers, and the supposed cause of explosion, together with references to the books or papers from which further information may be obtained. Of course many of the explosions have to be put down as uncertain in some of the particulars; but every year improves the record, as fresh information is obtained, and with the assistance of the members of this Institution it might be made far more perfect and extensive.

The total number of explosions here recorded is 1046, and they caused the death of 4076 persons and the injury of 2903. The causes assigned for the several explosions are very numerous, and are no doubt incorrect in many cases; but they may be generally stated as follows:—

397 are too uncertain to place under any heading; but of the rest

145 were from the boilers being worn out, or from corrosion, or from deteriorated plates or rivets.

137 from over pressure, from safety valves being wedged or overweighted, in some cases intentionally, or from other acts of carelessness.

125 from faulty construction of boiler or fittings, want of stays, or neglect of timely repair.

119 from collapse of internal tubes, generally from insufficient strength.

114 from shortness of water, or from scurf preventing the proper contact of the water with the plates; or from improper setting so as to expose the sides of the boiler to the flame above the water line.

9 from extraneous causes, such as effect of lightning striking down the stacks upon the boilers, or from fire in the building or explosion of gas in the flues.

1046 total number of explosions.

The exploded boilers were of the following descriptions:—

232 are not sufficiently described to place under any head; but of the rest

320 were Marine boilers of various forms.

141 were Cornish, Lancashire, or other boilers internally fired.

120 were Locomotive, or other multitubular boilers.

116 were plain Cylindrical boilers, externally fired.

64 were Balloon or haystack, wagon, Butterley, British-tube, elephant, or Trevithick boilers.

29 were Portable, agricultural, upright, or crane boilers.

14 were Heating apparatus or kitchen boilers.

10 were Upright boilers attached to puddling or mill furnaces at ironworks.

1046 total number of explosions.

The theories as to the causes of explosion have been numerous. In the early days of the steam engine, when the steam was used only as a condensing medium and the pressure in the boiler was frequently allowed to get below atmospheric pressure, many boilers were destroyed by the excess of the external atmospheric pressure becoming too great, causing them to be collapsed or crumpled up; and this led to the use of the atmospheric valve still found on old boilers. Even so lately as last year a boiler in the neighbourhood of Bury, Lancashire, has suffered in this way by collapse from external pressure; its appearance after the accident is shown in Fig. 4, Plate 43, which is copied from a photograph. The early explosions were so palpably due to the weakness of the boilers, which compared with those of the present day were most ill constructed, that no one thought of any other cause than the insufficient strength of the vessel to bear the expansive force of the steam contained in it. When the advantages of high-pressure steam became recognised, and the boilers were improved so as to bear the increased strain, the tremendous havoc caused by an explosion led many to think that something more must be required than the expansive force of the steam to produce such an effect; and they appear to have attributed to steam under certain conditions a

detonating force, or a sudden access of expansive power that overcame all resistance. To support this somewhat natural supposition, it was asserted that the steam became partially decomposed into its constituent gases, forming an explosive mixture within the boiler. That this belief is still sometimes entertained is seen from the verdict of a jury even in the present year, in the case of the explosion of a plain cylindrical boiler at Leicester, shown in Fig. 18, Plate 46, the real cause of which appears to have been that the shell of the boiler was weakened by the manhole. It seems hardly necessary to point out the fallacy of imagining decomposition and recomposition of the steam to take place in succession in the same vessel without the introduction of any new element for causing a change of chemical combination; but it is necessary to refer to this supposition, as the idea is shown to be not yet extinct.

Again it has been asserted that the steam when remaining quite still in the boiler becomes heated much beyond the temperature due to the pressure; and that therefore when it is stirred or mixed or brought more in contact with the water by the opening of a valve or other cause, the water evaporates so rapidly as to produce an excessive pressure by accumulation of steam. In support of this view the frequency of explosions upon the starting of the engine after a short stand is adduced; but it is very doubtful whether by this means a sufficient extra pressure could be produced to cause an explosion, unless the boiler had been previously working up to within a very small margin of its strength. Explosions are seldom caused by a sudden increase of pressure, but rather by the pressure gradually mounting to the bursting point, when of course the effect is sudden enough. Nor is it necessary in many cases to look for much increase of pressure as the cause of explosion; for it is far more often the case that the strength of the boiler has gradually degenerated by wear or corrosion, until unable to bear even the ordinary working pressure. It is so very easy, when examining the scene of an explosion, for the first cause of rupture to be confounded with the causes of the subsequent mischief, that in many cases erroneous conclusions have been arrived at in this way.

The most important points to find out in connection with any explosion are the condition of the boiler and all belonging to it immediately before the explosion, together with the locality of the first rent, the direction of the line of rupture, and the nature of the fracture; as everything occurring after the instant of the first rent is an effect and not a cause of explosion. As soon as the first rent has taken place, the balance of strain in the fabric is disturbed, and therefore the internal pressure has greatly increased power in continuing the rupture; and also the pressure being then removed from the surface of the water, which is already heated to the temperature of the steam, the whole body of the water gives out its heat in the form of steam at a considerable pressure, and thus supplies the volume of steam for carrying on the work of destruction. When thus quickly generated, the steam perhaps carries part of the water with it in the same way that it does in ordinary priming; and it has been thought by some that the impact of the water is thus added to that of the steam, to aid in the shock given to all surrounding obstacles.

It is seldom that one out of a bed of boilers explodes without more or less injury to the others on either side of it; but sometimes two boilers in one bed, or three, or even five, have exploded simultaneously.

The causes of boiler explosions may be considered under the two general heads of—

Firstly, faults in the fabric of the boiler itself as originally constructed, such as bad shape, want of stays, bad material, defective workmanship, or injudicious setting:—and

Secondly, mischief arising during working, either from wear and tear, or from overheating through shortness of water or accumulation of scurf; or from corrosion, in its several forms of general thinning, pitting, furrowing, or channelling of the plates; or from flaws or fractures in the material, or injury by the effect of repeated strain; or from undue pressure through want of adequate arrangements for escape of surplus steam.

There is no doubt that many of the early explosions were from faults of construction. The stronger materials now used were then found so difficult to manipulate that others easier to work were chosen, and often the shape of the boiler was only selected as the one easiest to make. The early boilers were made of copper or cast iron, with leaden or even wooden tops, and of the weakest possible shape. Such was the boiler used by Savery, shown in Fig. 40, Plate 51, and the Tun boiler and Flange boiler, Figs. 41 and 42. The very fatal explosion in London in 1815, referred to by the parliamentary commission previously named, was of a cast-iron boiler, which failed because one side was too thin to bear the pressure, as the casting was of irregular thickness. The steam being at that time used only at or below atmospheric pressure as a means of obtaining a vacuum by condensation for working by the external pressure of the atmosphere, so little was pressure of the steam thought of that boilers were proposed and it is believed were actually constructed with hooped wooden shells, like barrels, and internal fireplaces and flues of copper; and even a stone chamber was named as being a suitable shell for a boiler, with internal fireplace and copper flue passing three times the length of the inside and out at the top, like an ordinary stove and piping. These boilers must have been something like the sketches given in Figs. 44 and 45, and were intended to be exposed only to the external pressure of the atmosphere.

Cast iron was frequently used for the shell of boilers, with an internal fireplace and tubes of wrought iron, as shown in Fig. 46, Plate 51; and boilers of this construction are still to be found in use at some of the older works at the present day. As the outside shell and front plate are 1½ inch thick and are not exposed to any wear at all, these boilers are sufficiently strong. A duplicate front plate with set of tubes attached is always kept on hand in case of need. Another form of cast-iron boiler is shown in Fig. 43, made in several parts put together with flange joints, with an internal fireplace and flue also made of cast iron. When cast iron was used for the parts exposed to the fire in boilers intended for high pressure, it was sometimes employed in the form of tubes of small diameter and

proportionately thinner; as in Woolf's boiler, so much spoken of in the evidence before the parliamentary committee of 1817. This boiler, shown in Fig. 47, consisted of nine cast-iron pipes, about 1 foot diameter and 9 feet long, set in brickwork so that the flame played all round them. These small tubes were connected with another of larger size placed transversely above them, forming a steam receiver, and this again with a still larger one, which formed a steam chamber. No details of any explosions of the three last mentioned boilers have been obtained; but it is known that the cast iron was found a most treacherous material, especially when exposed to the action of the fire; and that the effect of explosion was very disastrous, because the boiler burst at once into many pieces, each of which was driven out with great velocity, and the danger was not mitigated by the circumstance of large masses holding together, as is found to be the case with wrought-iron boilers when exploded.

When wrought-iron boilers came into use the shapes were most varied, and the dimensions much larger than before. One of the earliest was the Wagon boiler, shown in Fig. 48, Plate 52, with round top and plain flat sides, which could only be made to bear even the smallest pressure by being strengthened with numerous stays. In most cases of explosion of this class of boiler the bottom was torn off, owing to the angle iron round it being weakened by the alternate bending backwards and forwards under each variation of pressure, as all the sides and the bottom must be constantly springing when at work. Such was the explosion at Chester in 1822, and many others. This shape was soon improved in its steam generating powers by making the sides concave instead of flat, as shown in Fig. 49, so that the heating surface was greater and also in a better position to receive the heat from the flame in the flues. This shape was further elaborated by rounding the ends, as in Fig. 50, and in some cases making the bottom convex to correspond with the top, as in Fig. 51. All these forms however still required numerous stays to retain them in shape, the safety of the boiler being dependent upon the stays; and numerous explosions show the

weakness of these boilers. They generally gave way at the bottom, as in an explosion that occurred at Manchester in 1842, where the boiler had been weakened by frequent patching; they also sometimes exploded through the failure of the stays.

A very early improvement in the right direction consisted in making the shell circular; and some few large boilers still exist that were made completely spherical, as shown in Fig. 52, so that the whole of the iron was exposed to tension only, and required no assistance from stays, and the boiler had no tendency to alter its shape under varying pressure. This shape however had the great disadvantage of possessing the least amount of heating surface for its size or cubic contents; and also it was very liable to injury from sediment on the bottom, which accumulated on the most central spot. The spherical form was therefore soon modified into the shape shown in Fig. 53, by making the bottom more shallow, although still convex; and afterwards by putting flat or concave sides and a flat or concave bottom, with the angle constructed either of bent plates or angle iron, as in Figs. 54 and 55, which represent the forms known so well in the Staffordshire district as the common Balloon or Haystack boiler. Many of these have been made of very great size, measuring as much as 20 feet diameter, and containing so much water and steam as to be most formidable magazines for explosion. Perhaps no form of boiler has exploded more than this, partly because of the great number that have been used, but chiefly because of the inherent weakness of the shape. The records however have not been obtained of the great majority of these explosions, because they seldom caused sufficient damage or loss of life to attract much attention, as these boilers generally worked in isolated positions at collieries. The bottom is only prevented from blowing down into the fireplace by numerous stays from the top, and the angle iron round the bottom of the sides is much tried by the constant springing of the plates under every alternation of pressure; and the weakness thus occasioned is increased by the angle resting on the brickwork and being exposed to corrosion. The effect of this continued alternation of strain is well shown by the elastic model exhibited.

Notwithstanding the dependence of these boilers upon stays for their strength, many have been made as large as 12 and 15 feet diameter without stays; and explosion sooner or later has been the consequence. Such was an explosion that took place at Smethwick in 1862, which is shown in Fig. 5, Plate 43. As the force of the explosion was only slight, the effect of the bottom giving way, and the consequent rolling over caused by the reaction of the issuing steam and water, is clearly seen. Another example that occurred at Wednesbury in 1862 is shown in Fig. 1, where the explosion was rather more violent, the bottom of the boiler being torn off all round and left upon the firegrate, and rent nearly into two pieces; while the top and sides were thrown some height in one mass, and were only put out of shape by the fall. The weakness of this boiler had been further increased by making the bottom angle of angle iron, as shown enlarged in Fig. 2, with a ring of flat plate A interposed between the angle-iron ring and the concave bottom of the boiler; so that all the effect of the springing of the bottom, as shown by the dotted lines, was thrown upon the angle iron, which was accordingly found cut off all round. Had the concave bottom been made to rise direct from the angle iron, as in Fig. 3, the springing could not have been so great, and the angle iron would only have had to stand the shearing strain of retaining in its place the rigid bottom; but as about one foot all round the bottom was flat, and the concavity was only in the central part, the angle-iron ring had to bear an up and down strain, as shown by the dotted lines in Fig. 2, and the bending action was more severe than it would have been if the bottom had even been made quite flat all over.

A further form of the Balloon boiler is shown in Fig. 56, Plate 53, where the heating surface of the bottom is increased by an internal central dome-shaped fireplace, with an arched and curved flue conducting the flame through one revolution within the boiler before passing again round the outside. This construction however must necessarily have diminished the strength of the boiler greatly. In the drawing the top of the boiler, as indicated by the dotted lines, is removed to show the interior.

The desire to add to the strength of boilers by lessening the diameter of the shell led to the construction of the Plain Cylindrical boilers. They were made first with flat ends of cast iron, which frequently cracked and gave way when exposed to the fire, as described in many of the early American explosions. The flat ends when made of wrought iron, as shown in Fig. 57, Plate 53, are exposed to the same strain as the bottom of the balloon and wagon boilers, and are constantly springing with variation of pressure like drum heads, causing injury to the angle-iron joint. They also require long stays through them to hold in the ends, and these are subject to so much vibration that they seldom continue sound for long together, especially when joined with forked ends and cotters.

As the flat ends of such boilers are always being sprung by each alternation of pressure into a more or less spherical shape, as shown by the elastic model exhibited, this consideration no doubt led to the ends being made hemispherical, as shown in Fig. 58; and plain cylindrical boilers with these hemispherical ends are now so commonly used that they far outnumber any other form of boiler. Their shape renders them very strong, as the whole of the iron is in simple tension, and internal pressure has no tendency to alter the shape, as is shown by the elastic model exhibited. There is one circumstance very much in favour of the plain cylindrical boilers, and that is that they can be so easily cleaned and repaired, as a man can stand properly at his work at every part and the whole of the interior surface is exposed equally to view. They are of course exposed to all the evils of boilers externally fired, the part under greatest strain being weakened by the action of the fire; and the bottom is also exposed to injury from accumulation of mud and chips of scurf, which cannot be prevented from falling there, and lying upon the part exposed to the direct action of the fire. When made of great length, such as 70 or 80 feet, as is the practice for applying the waste gas from blast furnaces, these boilers are also liable to seam-rips or "broken backs," owing to the greater expansion of the bottom exposed to the fierce flame for its whole length, than of the top which is kept cooler by exposure to the air; and it would

therefore be better to have a succession of short boilers, rather than only a single one, where great length is required.

One boiler has been seen by the writer where extreme length was avoided by curling the boiler round until the ends met, forming a Ring or Annular boiler. This boiler is shown in Fig. 59, Plate 53, and is 5 feet diameter with 25 feet external diameter of the ring, or a mean length of about 63 feet; it has been found to work well for some years, although exposed to the heat of six puddling furnaces.

Explosions of plain cylindrical boilers have been very frequent indeed, although they have not caused a proportionate number of deaths, because they work usually in isolated positions at colliery and mine engines. The sketch shown in Fig. 6, Plate 44, represents an explosion that occurred at Darlaston in 1863, and illustrates the way in which these boilers usually explode. They generally open first at a longitudinal seam over the fire, which has become deteriorated by accumulations of scurf preventing proper contact of the water, so that the plates become overheated, their quality injured, their edges cracked or burnt, and the rivets drawn or loosened. The rent generally continues in the longitudinal direction to the sound seam beyond the bridge at the one end, and at the other end to the seam joining the front end to the shell; and then runs up each of the transverse seams, allowing the rent part of the shell to open out flat on both sides, and liberating both ends of the boiler, which fly off in opposite directions. Of course it is seldom that an explosion is quite so simple as this, as the direction of the flight of the various pieces is so much influenced by the last part that held in contact with the main body of the boiler. The want of due observation of this point has often led to erroneous conclusions.

In the explosion shown in Fig. 7, Plate 44, and in the model exhibited, which occurred at Westbromwich in 1864, the lower part of the side of an upright boiler was blown out; and the liberated part was also divided into two pieces, each of which fell some distance behind the boiler, in an opposite direction to the side from which they came. The explanation of this became obvious on examination, as the cause of the rupture had been the corrosion of

the bottom, and the rent had run up the seams until it met the angle iron of the side tubes, round which it ran to the first seam above. This seam acted as a hinge on which the ruptured pieces turned, and they swung round so violently that they were wrenched off, but not before they had pulled the boiler over and received the diverting force which gave them their direction, for they flew off at a tangent to the circle in which they had swung round on the sound upper seam as upon a hinge.

In order to avoid having a large diameter for plain cylindrical boilers, especially where exposed to the fire, boilers have been used that have supplied the required steam power by a combination of several cylinders of small diameter. One of these, known as the Elephant boiler, has been so much used in France that it is sometimes called the French boiler; it is shown in Fig. 61, Plate 53, and consists of two cylinders of small diameter connected by upright conical tubes to a large cylinder above. Another form called the Retort boiler, shown in Fig. 60, has been described at a previous meeting of this Institution (see Proceedings Inst. M. E. 1855 page 191). The disadvantages of these two combinations of plain cylinders are that they are not easy to clean or examine internally, and also there is not free exit for the steam, which has to find its way along small channels, and carries the water away with it, causing priming, and also retarding the generation of steam and endangering the boiler plates. With a view to strengthen the plain cylinder made of wrought-iron plates, the seams are sometimes made to run diagonally, as shown in Fig. 62, on the principle that, as the longitudinal is the weakest seam and the transverse the strongest, a diagonal between them gives the greatest amount of strength to the boiler as a whole.

Plain cylindrical and wagon boilers have for many years been made with internal tubes of various shapes and arrangement, through which the flame passes to add to the heating surface. These are shown in dotted lines on the previous drawings of wagon boilers, Figs. 48 and 49. They are also shown in Fig. 63, Plate 54, where a tube passes from over the fire to the front of a plain cylindrical

boiler: in Fig. 64 two tubes pass from the sides to the front: in Fig. 66 the tube passes from the back, but returns over the fire and passes again to the back: and in Fig. 65 a tube from the back passes out through a cross tube in each side. The boilers in all these cases are fired externally. This addition of tubes has tended very much to increase the size of these boilers in order to make room for the tubes. These boilers are now found of 9, 10, and even 11 feet diameter; and this large shell being fired externally is exposed to the same dangers as those described in the plain cylindrical boiler, while it is not so easy to keep clean on account of the obstruction offered by the internal flues. When the flame has passed under the whole length of the bottom of these large boilers before going through any tube, it is doubtful whether the heating surface of the tube helps much in the generation of steam; but the tube is of use in reducing the quantity of water in the boiler, as it occupies a considerable space.

Explosions of these boilers have sometimes taken place by collapse of the tubes, but much more generally by the failure of the shell over the fire, as shown in the sketch Fig. 8, Plate 44, representing an explosion that occurred at Wolverhampton in 1865, in which the first rent took place in a seam over the fire where frequent repair had led to a considerable length of longitudinal seam being in one continuous line. The four plates over the fire parted and opened out until they had ripped two seams completely round the boiler; and the plates were thrown in one flat piece, as shown, upon a bank behind. The main body of the boiler with the tubes was turned over, and the front end blown away.

A modification or amalgamation of several of the forms of boilers already mentioned led to the construction known as the Butterley boiler, shown in Fig. 72, Plate 55, with a wagon-shaped end over the fire, continued in a single tube within a plain cylindrical shell beyond. This boiler has been found to generate steam very rapidly; but the extreme weakness of the construction over the fire and along the tube, especially at the part where the front end of the tube widens out in a bell mouth to meet the wagon-topped fireplace, has led to

so many explosions that few boilers are now made of this form. A very early explosion that occurred at Edinburgh in 1821 was of a boiler somewhat of this shape, only that the wagon-topped fireplace was much longer. Other explosions of this form of boiler occurred at Ashton-under-Lyne in 1845, at Wolverhampton in 1854, and at Tipton in 1856.

The desire to economise fuel led to placing the fire inside the boiler, in a tube running from end to end, as shown in Fig. 67, Plate 54; and the great number of boilers of this form used in Cornwall gave it the name of the Cornish boiler. The exceedingly good duty performed by these boilers led many to believe them the most perfect for economy and durability; but the great number of explosions, or more properly of collapsed flues, that have happened, have altered this opinion, and led to the double-flue boiler shown in Fig. 68, in which not only is the heating surface increased but the strength also, by having two tubes of smaller diameter in the same shell. There are a great many varieties of the two-tube boiler, which have been made for the purpose of obtaining various particular results. In some cases the two tubes have been made to unite into a single tube immediately behind the fires, forming what is known as the Breeches-tube boiler, as shown in Fig. 69; and in other instances the outside shell of the boiler has been made oval, as shown in Fig. 70, with the two tubes continued through from end to end. The heating surface has also been increased, and the strength of the main tubes, by placing smaller transverse tubes across them at right angles; but these advantages are gained by increased complication, leading of course to greater difficulty in examination and repair.

The frequent failure of tubes by collapse when used for high pressures, and also the results of careful experiments, led to the simple addition of strengthening rings of different makes around the exterior of these tubes, by which the shell and the tubes are rendered of equal strength. It has taken considerable time for the belief in the weakness of large tubes when exposed to external pressure to become general, and a great many boilers

are still made and used having even large tubes without the strengthening rings; and in some districts such boilers are used in great numbers and at far higher pressures than can be considered judicious. In more than one bed of boilers one boiler after another has exploded by the collapse of the tube from the want of strengthening rings, and yet these have still been believed unnecessary; and the cases of isolated boilers of this construction where the large tubes have collapsed are extremely numerous, yet any other reason than the weakness of the tube has been considered more probable as the cause of explosion. A sketch of a boiler with collapsed flue is given in Fig. 11, Plate 45, which exploded at Burton-on-Trent in 1865; and it is selected from many others because it was a new boiler, well made and mounted, and was a good example of the weakness of a large tube to resist high external pressure when made of great length without the support of strengthening rings.

There are a great many advantages in the tubular boiler internally fired. The shell which is exposed to the greatest tension is not also exposed to the first action of the fire. The fire is in the midst of the water, so that the greatest effect is obtained from it; and the heating surface immediately over the fire, from which most steam is generated, has not so great a depth of water above it for the steam to pass through as in the externally fired boilers heated from the bottom. The tubes also act as stays to the ends; and the mud in the water falls off the tubes, where it would do mischief, and settles on the bottom, where it is comparatively harmless.

These tubular boilers are however subject to disadvantages peculiarly their own. It is not so easy to move about within them for cleaning and examination as in the plain cylindrical boiler, as the tubes fill up the space so much. The difference of expansion between the highly heated tube and the comparatively cool shell produces a strain, which causes the ends to bulge out; or if the ends are made rigid, the strain sets up a contortion in the tube, which causes furrowing of the plates by making the iron softer or more susceptible of corrosion in certain lines of strain. Notwithstanding these drawbacks however this form of boiler is an excellent one.

Many modifications in the forms of boilers have been made to enable the manufacturers to use the waste heat from various processes, especially from the making of iron. The plain cylindrical boiler has been used in this way, with sometimes as many as eight puddling furnaces made to work upon one boiler. One of the earliest special arrangements for this purpose was the Upright boiler with central tube, shown in Fig. 73, Plate 55, which was originally made for two furnaces; and about 7 feet diameter and 16 feet high. The size has since been increased to 10 feet diameter and 28 feet high, as shown in Fig. 74. These boilers are made for one, two, three, or four puddling furnaces; and consist of a cylinder with spherical ends, standing upright, with a central tube from the bottom to about half the height, into which the side tubes join. The heat from each furnace plays over a portion of the shell, and then passes through the side tubes and down the centre tube into the underground flue to the chimney.

These boilers have many good points: there is great heating surface; and the shell being heated all round does not strain the plates and seams by unequal expansion so much as in the horizontal plain cylindrical boiler heated only at the bottom; and as both ends are spherical there is no alteration of shape under internal pressure. Moreover in consequence of the upright position of the boiler a safe depth of water can easily be maintained, and yet the steam is taken off so high above its surface that there is little priming; and every part can most easily be cleaned and examined, as a man can stand upright both in the boiler and in the flues. But the great drawback to this class of boilers is that they must stand in the midst of the workmen; so that, although they are not more liable to explode than any other form of boiler, yet when they do burst they necessarily endanger more lives than is usually the case with other boilers that can be placed more away from the men employed at the works. Should anything arise with the boiler to make it desirable to withdraw the fire, this cannot be done without much delay, as the furnaces have to be stopped and the iron run out. Also an explosion can hardly happen without some of the melted iron being scattered among the men at work.

Some of the most fatal explosions of these boilers have arisen from careless construction. Such was the case in an explosion at Dudley in 1862, shown in Fig. 9, Plate 45, where the crown plate forming the top of the centre tube was attached to the sides of the tube by so slight an angle iron, as shown enlarged in Fig. 10, that the pressure of steam on the flat crown plate fairly sheared the angle iron through, and allowed the plate to be blown down the centre tube into the chimney flue, whereupon the boiler was violently thrown off its seating by the reaction of the issuing steam and water thus liberated.

The double-tube horizontal boiler is also used in connection with iron-making furnaces in many places, one furnace working into each tube. Although by this arrangement the boiler can be placed a little further from the workmen, some very fatal explosions have happened to such boilers, as at Masborough in 1862.

Single-furnace boilers have been much used in the form of a single-tube boiler standing on end, as shown in Fig. 75, Plate 55, with the flame passing up the tube, which is continued in the form of a chimney on the top of the boiler. The tube passes through the steam at the top, so that the plate is not protected from overheating by contact with water; and this has caused explosion in some instances, although the tube has been lined on the inside with firebrick to shield the plate from the flame. Another great disadvantage of this Chimney boiler is that the space between the tube and the shell is so narrow that it is almost impossible to examine or clean it internally.

A further arrangement for a single-furnace boiler is the Elbow boiler, shown in Fig. 71, where the two difficulties mentioned in the previous boiler are avoided.

Many internally fired upright boilers of various shapes have been constructed to suit various purposes. One of a large size that has been at work many years is shown in Fig. 76, Plate 55, with an internal fireplace and a suspended cone and cross tube for increasing the heating surface. This boiler is set in brickwork in such a way that the heat passes through the side tubes and round the exterior shell before going off to the chimney.

A very fatal explosion at Stoke-upon-Trent in 1863 resulted from an attempt to work a boiler of somewhat the same general form, but without the same careful attention to the details of construction. This boiler is shown in Fig. 12, Plate 45; the internal fireplace is of conical shape, 4 ft. 6 ins. diameter on the top and 6 ft. 10 ins. at bottom, and was joined to the external shell by a flat annular bottom. Almost the first time it was worked at high pressure the conical fireplace collapsed, breaking off at the seam at the top of the cone, and blowing down upon the grate, as shown in Fig. 13. The flat bottom was then left without the support of the cone and side tubes, and gave way all round the outside angle iron; and the top flew up a great height into the air, and fell a crumpled heap, as shown in the sketch. In this case the only wonder is that a boiler of such weak construction worked at all without explosion.

There yet remains to be noticed a very large and varied class of boilers that have been designed with the express object of avoiding explosion. Some of these, made of cast-iron pipes of small diameter, have already been referred to. When steam carriages were first constructed, boilers were tried made of a cluster of small pipes, set both upright and horizontally, connected with a general receiver and with each other by still smaller pipes. These were found to have such small circulation of water that they very soon burnt out, and also led to much priming. Afterwards narrow chambers made of corrugated plates set like the cells of a battery were tried, but without much success. The multitubular boilers of the locomotive type soon superseded all others as quick steam generators, and until lately they have been considered as almost absolutely safe from explosion. It is found however that the barrel of these boilers is peculiarly liable to furrowing, owing to the strain weakening the iron in certain lines. Perhaps no boiler shows more clearly than the locomotive how necessary it is that every part should be open to examination; and also how unwise it would be to use for stationary purposes small cramped up boilers, only intended to meet the necessities of locomotion. Many explosions of locomotive boilers have taken place; but it is not necessary to give details in

this paper, as they are fully given in the published official reports of the government inspectors.

Among the forms of boilers designed to obtain very rapid generation of steam, combined with increased safety from explosion, may be specially named that consisting of a system of small pipes within a shell with an artificial circulation of water, and also the boiler consisting of a cluster of cast-iron spheres, both of which have been described at previous meetings of the Institution (see Proceedings Inst. M. E. 1861 page 30, and 1864 page 61); but neither has been much used in this country at present. The boilers also which consist chiefly of small tubes hanging down into the fire, with smaller tubes or other arrangements within them for securing a natural circulation, deserve mention, as they appear successfully to accomplish that end.

The principle of all these small boilers appears to be that only a small quantity of water should be contained in them, so that there should not be a reservoir of danger in the shape of a mass of highly heated water ready to be converted into steam if a rupture takes place: and it cannot be denied that this is an advantage. But on the other hand these boilers of small capacity, which evaporate their whole contents in a few minutes, are subject to new dangers from that very cause; and although admirably adapted for purposes where steam is wanted quickly on a sudden emergency, as in the case of fire engines, or where the generating power required varies each moment, as in the locomotive, they are for the most part ill adapted for ordinary stationary purposes, such as the mill or the colliery. They require constant firing and vigilant attention to the feed, and cannot be left for a time with safety like the ordinary stationary boilers. It has to be borne in mind also that the very reservoir of danger so much dreaded is also a reservoir of power, which assists in the steady maintenance of the machinery in motion. The large mass of water heated to the evaporating point, the heated brickwork of the flues, and the large fireplace, are so many assistances to regularity, and enable the man in charge to attend to his other duties without the risk of spoiling the boiler or letting down the steam by a few minutes' absence from the stoke hole. Steam

employers are found at present to prefer the known dangers of the large boilers to the supposed safety of small boilers, which they fear are troublesome in practice.

Many of the early boilers were rendered weak by the injudicious manner of arranging the seams. The longitudinal seams were made in a continuous line from end to end, as shown in Fig. 57, with the transverse seams also continued completely round the boiler, so that at the corner of each plate there were four thicknesses of iron. The crossing of the seams, as in Fig. 58, adds much to the strength, and also often prevents a rent from continuing forward to a dangerous extent.

It is scarcely requisite to mention the necessity of good material and workmanship to secure strength in a boiler, however perfect the design. If the plates are of weak or brittle iron, or imperfectly manufactured, they will never make a good boiler. Apart from the strain upon the boiler when at work, the iron has to undergo the strain of the necessary manipulation, shaping, and punching, during the construction of the boiler. If the plates forming the boiler are not well fitted to their places before the rivet holes are made, the errors have to be partially rectified by using the drift in the holes to an unwarrantable extent, and then using imperfect rivets to fill up the holes that do not correspond with each other; and the mischief is too frequently increased afterwards by excessive caulking, in the endeavour to stop the leaking which is sure to show itself. In this way a boiler is often exposed to most unequal internal strain between its several parts before it is set to work at all; and when the heat is applied to it, the mere expansion causes undue contortion, and leads to seam rips, and ultimately to disaster. Several specimens of faulty rivetting and caulking are exhibited to the meeting, and a sketch of one of them is shown in Fig. 35, Plate 50.

The strength of a boiler is often very much lessened by the injudicious manner in which the mountings are fixed upon the boiler, and many explosions are the consequence of this defect. Not only are a great many holes for fittings cut out of the boiler in one

line, but these holes are made needlessly large. Steam domes are often so placed as greatly to weaken the shell of the boiler, the hole cut out of the plate being made the full diameter of the dome; and in some cases the domes or steam chests have been made square or rectangular, so as to weaken the shell still more, as shown in Fig. 14, Plate 46.

Manholes are often a source of danger, if not properly arranged and duly strengthened. Even in very small boilers they are often placed with the longest diameter in the longitudinal direction of the boiler, so that the shell is greatly weakened, as in the sketch, Fig. 17, Plate 46, of an exploded boiler at Walsall in 1865. This boiler was 5 ft. 3 ins. long and 2 ft. 6 ins. diameter, and yet the manhole was 18 inches by 13 inches, and placed within a few inches of one end. The end was fastened in by angle iron, which was not welded, and consequently there was so little strength at the small portion of the shell between the end and the manhole that it gave way and liberated the end and the manhole lid, after which the main body of the boiler was thrown by the reaction across several streets to a great distance.

A somewhat similar injudicious arrangement of the manhole is shown in Fig. 16, Plate 46, where a manhole 17 inches by 14 inches was cut out of the flat top of a steam dome only 2 ft. 6 ins. diameter, without any strengthening ring to compensate for it. The repeated strain of screwing up the manhole lid, combined with the pressure of the steam, caused the lid to force its way out through the plate and blow away. This explosion occurred at Birmingham in 1865.

The preceding examples have shown how explosions often result from faults in the construction of boilers; and the following instances illustrate the explosions caused by mischief arising during working. A boiler perhaps more than any other structure is subject to wear and tear; and let it be worked ever so carefully, it will seriously deteriorate. The wonder is, considering the work they have to perform, that so many boilers are found which have worked twenty, thirty, or even fifty years without explosion. The terms wear and

tear however are too vague for this subject, and the mischief met with must be considered under distinct heads.

There is no doubt that the thing most to be dreaded for boilers is corrosion; because when the plate is once thinned, it cannot be strengthened again, but must remain permanently weakened. Corrosion the more deserves attention because it is easily detected by moderate vigilance, and can generally be prevented by moderate care, or by the boilers being so arranged that they can be readily examined in every part. Corrosion has been the direct and unmistakable cause of a very large proportion of the explosions that have happened: it occurs both inside and outside the boiler, according to circumstances, and attacks the iron in various ways and in different places.

Internal corrosion sometimes takes place from bad feed water, and its effects are different in extent in the different parts of the same boiler. It very seldom thins the plate over a large surface regularly, but attacks the iron in spots, pitting it in a number of holes. These are sometimes large, as if gradually increasing from a centre of action; and sometimes small, but so close together as to leave very little more space whole than that which is attacked. A very curious example of the latter is exhibited to the meeting, and shown in Figs. 27 and 29, Plate 48, cut from the lower part of the shell of a large tubular boiler externally fired. The corrosion was greatest along that part of the shell most exposed to heat, and was so extensive that two boilers exploded simultaneously. The boilers had been at work sixteen years, but the corrosion commenced about eight years before the explosion, when the feed water was rendered corrosive by being obtained from some iron mines. This explosion occurred at Aberaman in 1864. The corrosion had been seen going on for years, and was not considered sufficient to cause danger; but the depth to which it extended through the thickness of the metal is seen in the full size section, Fig. 29. Another sample equally curious is exhibited to the meeting, and shown in Figs. 28 and 30, taken from the sweep plate over the fire in a plain cylindrical boiler which had worked about ten years. The feed water was occasionally bad, and attacked the iron

over the area DDD, where unprotected by scale. The protection afforded by scale against occasional corrosive feed water is worthy of notice. In the two specimens exhibited it is seen that the protection has been perfect where the scale has not been chipped off; and the edge of the sound part projects over the hollow, as seen in the full size sections, Figs. 29 and 30, the corrosive water having eaten away a larger area beneath than that through which it first entered the surface of the iron.

Internal corrosion is frequently observed where boilers are fed from canals or streams in the neighbourhood of chemical works from which corrosive matter is discharged at intervals into the water. The corrosion takes place in isolated spots, but causes deep holes; which seems to be accounted for on the supposition that the scale previously upon the plate cracks during the cooling of the boiler for cleaning, and forms a blister, so that a piece of about 2 inches area is raised slightly from the iron. When the boiler is again put to work, this blister becomes filled with the corrosive water, which is held there without circulation and causes corrosion. When the boiler is again emptied these blisters may be seen, and if broken show the blackened water and the injured surface. In future working each of these blisters forms a constant unprotected point for attack. It is frequently seen further that such corrosion is arrested if water be used which deposits scurf; but fresh blisters and renewed corrosion will result from a return to the use of the bad water.

The internal corrosion called furrowing has proved a frequent cause of explosion, especially in locomotive boilers. It differs from other corrosion by being in deep narrow continuous lines with abrupt edges. It will sometimes go completely through a plate; and is found where a sudden change of thickness occurs, either along the lines of the seams, or opposite the edge of angle-iron attachments. This effect is supposed to be due to the alternate springing of the plates under each variation of the pressure or temperature, causing the line of least resistance to receive a strain somewhat similar to that produced by bending a piece of iron backwards and forwards for the purpose of breaking it. This line of injury

is exposed to constant attack from corrosion, because the scurf is always thrown off from it.

External corrosion is a far more frequent cause of explosion in stationary boilers; and it arises from many causes. The most frequent cause, although the most easily detected, is leakage from the joints of the fittings on the top of the boiler, which are too frequently attached by bolts instead of rivets. This evil is much increased when the boilers are covered with brickwork, which holds the water against the plates, and hides the mischief from observation. It is astonishing to find how much damage is allowed in this way to go on without attention, until the tops of boilers are corroded so thin that little holes burst through. These are sometimes found stopped with wooden pegs or covered by screwed patches of plate, either of which cause leakage that hastens the mischief, as shown by the sample exhibited. Boilers exposed to the weather will of course become corroded like anything else made of iron and not painted; and yet so much mischief is sometimes caused by leakage beneath improper covering that exposure may almost be said to be the smaller evil of the two, as it is better to see what is going on than to rest in false security. No covering will be found cheaper or better in the long run than a roof, which prevents the loss of heat by exposure, and yet allows free access to all the fittings and joints on the top of the boiler.

Some examples of the evils of covering can be given that have come under the writer's observation. A set of boilers had been well covered by arches of brickwork, so built as to keep out all water, and also set so as to touch the boilers only at intervals, leaving a space generally of a few inches. After about seven years' working the whole of the tops of the boilers were discovered to be dangerously thin, and had to be renewed. The cause was leakage from the joints of fittings and seams of the boilers, and the issuing steam had been drawn along the space between the boilers and the arches, and had escaped at a place where it had not attracted notice. In another case a somewhat similar set of boilers were covered with ashes, to prevent the loss of heat by radiation; and the rain and the leakage

beneath the ashes, in conjunction with the corrosive matter from the ashes themselves, thinned the tops of the boilers to a dangerous extent in less than two years. A sketch of the corrosion caused in this instance by covering with ashes is shown in Figs. 31 and 33, Plate 49. Similar mischief has been noticed in boilers covered with sand, as shown in the sketch Figs. 32 and 34, which represents an instance of corrosion after eight years' working; although nothing forms a better covering than sand for preventing loss of heat by radiation. In both these examples it will be seen that the corrosion has continued until the thickness of the plate has been so eaten away that a hole has been burst out at SS. A very good covering is formed by brickwork in cement; or various cements made for the purpose, which adhere to the surface of the plate and yet show leakage; or such materials as sacking or felt; or sheet-iron casing leaving about 6 inches of air space all round the boiler. But all these have the great objection that they hide the boiler from inspection, except by the expensive process of removing the covering; and in this way dangers that have caused explosion have remained hidden from observation.

Explosions have also taken place from general corrosion of the surface of the boilers in the flues. A new boiler which was set on sidewalls built upon a foundation of porous rock was found to have become corroded all along the bottom in less than two years, owing to the dampness which rose from the foundations causing a constant presence of vapour. The corrosion was peculiar, and more like that found on old iron left for a long time in a damp place; for the iron plate fell to pieces when touched, and large flakes could be raised from the surface, and the greater part of the thickness of the plate could be removed with the fingers. Somewhat similar corrosion had taken place in a boiler which exploded at Loughborough in 1863; the bottom of the shell became rent at the corroded part, and as the fracture continued spirally round the boiler several times, nearly all the shell was peeled off in the curious manner shown in Fig. 15, Plate 46. The explosion shown in Fig. 19, which occurred at Leeds in the present year, also arose from corrosion of the bottom of the boiler.

The greater part of the corrosion found in the side flues of boilers is caused by the leakage of seams. Many boilers are emptied for cleaning as soon as work is over on Saturday night, and long before the brickwork of the fireplaces and flues has cooled; and consequently the boiler, having no water in it, is made much hotter than it ever is in working, and the seams are injured and sprung and the rivets loosened by the extra expansion so caused. This is sometimes done intentionally, in order to loosen the scale by the greater expansion of the iron than of the scurf. When the boiler is again set to work, the seams and rivets leak and cause that corrosion which is called channelling. This has been observed to occur to such an extent that all the seams in a boiler have been seen thus corroded; and the same has sometimes been found in all the boilers in a large manufactory. Specimens of this channelling are exhibited to the meeting. One in particular, shown in Figs. 38 and 39, Plate 50, deserves attention, as it shows the effect of a jet of steam and water from the leaking rivet R, in cutting a series of channels into the plate along the course of the dotted lines EEE, and producing a hole in the plate at S. This corrosion had been going on for about four years, but was in a part of the boiler seldom seen in ordinary examination. Many explosions have resulted from this form of corrosion; for when a rent is once made, the fracture continues along the thinned channel of the plate.

The corrosion most to be dreaded, because most difficult to detect, is that which takes place where the boiler is in contact with brickwork; and it is found alike in all forms of boilers set in brickwork. When found at the part where the side flues are gathered in at the top against the boiler, it is usually occasioned by the leaking of fittings or feed pipes, or by rain being allowed to run between the boiler and the brickwork. More than one explosion has been caused by the droppings from a roof being allowed to fall upon the tops of the flues. When the corrosion is found at the point where the bottom flue walls touch the boiler, it is frequently caused by the leaking of seams that have been strained by the weight of the boiler; and this often arises from want of care to replace the brickwork, after repair of the boiler or flues, in such a position as

to take again its proper proportion of the weight of the boiler. Cases have been met with where the shape of the bottom of large boilers has been quite altered by such means. The brackets on the sides of heavy boilers have not only been strained so that the rivets or bolts have leaked and caused corrosion, but they have also bent or cracked the side plates of the boiler. The bracket shown at B in Fig. 14, Plate 46, made of only an angle iron with a piece of plate attached, is especially liable to cause injury if the brickwork is not rebuilt close up to the angle iron, as the leverage is so great. This is avoided by the better form of bracket shown at C, consisting of an elbow of flat bar-iron rivetted at top and bottom to the boiler.

In the old balloon and wagon boilers the angle where the bottom joined the sides scarcely ever remained sound for long when in contact with the brickwork, and many of those that exploded have been found almost corroded through where they stood upon the brickwork. The explosion before alluded to and shown in Fig. 7, Plate 44, was caused by corrosion of the bottom of the boiler where it was set on the brickwork. Many boilers are so set that the brickwork of the flues is made to follow the shape of the boiler, with as little space between as possible; but the slight advantage gained in increased heating effect is far outweighed by the impossibility of getting into the flues for examination. It is only by having the flues sufficiently roomy that proper examination can be made, and that the indications on the brickwork of leaking can be seen and remedied, and corrosion arrested. A remarkable case of corrosion occurred in a boiler with an oval shell, set upon a middle wall. The flues were too narrow for a man to enter, and a leak in the bottom was only discovered by the boiler nearly running empty while the engine pumps were standing for a short time. It was subsequently found that the whole bottom where it rested on the wall was extensively corroded in a continuous line, and that explosion was only prevented by the numerous stays across the bottom to compensate for the oval shape. Fig. 24, Plate 47, shows the position and extent of the corrosion, and the plate was completely in holes at the parts indicated by the black marks. This corrosion was supposed to have been going on for about three years.

It is sometimes asserted that corrosion cannot be the cause of an explosion, because the corroded place would simply give way and let off the steam harmlessly, or at least the boiler would not be displaced from its seating. When the corrosion is only local, and surrounded by sound plates of sufficient strength to arrest the extension of the fracture, this may be the case, as in an explosion at Sheffield in 1865, shown in Fig. 25, Plate 47, where a piece of plate was blown out on one side of the boiler, allowing the steam and water to escape without displacing the boiler; the thickness of the plate at that part had been reduced to 1-8th inch by corrosion in about $1\frac{1}{2}$ years, which had been caused by leakage at the seams from inefficient repair with bolts instead of rivets, and also from the moisture having been allowed to be kept against the plate by the brickwork. But even under such circumstances, if the piece blown out should be from the bottom, the whole boiler may be thrown a great distance by the reaction of the issuing steam, as in an explosion at Leeds in 1865, shown in Fig. 23. If the corrosion extends for any length, the first rent is almost sure to continue until a complete explosion is the result. Several of the small models exhibited to the meeting show the line of fracture in various cases of explosion. One shows the appearance of a plain cylindrical boiler after explosion caused by corrosion along the whole length where it rested on brickwork; this explosion occurred at Wigan in 1865, and a sketch of it is given in Fig. 22.

Many explosions of boilers have been caused by accumulation of scurf. The mischief is not so much from scurf being gradually deposited all over the interior of the boiler to a dangerous thickness, as from the chips off the sides falling in heaps on the bottom. The plate beneath this accumulation becomes overheated, because not in contact with the water, and softens and sinks down into a "pocket," which if unnoticed will soon burn quite through. If the scurf that has caused the mischief is thick and hard enough to resist the pressure for a little time, the hole enlarges, until the scurf suddenly gives way and allows the contents to issue so violently as to disturb the boiler, or at least to blow the fire out of the grate. Such was

an explosion at Bilston in 1863, where a large plain cylindrical boiler 9 ft. diameter was heated by three large fires placed side by side along the bottom; and a large "pocket" burst out over the third grate, and scalded the attendant to death. A similar pocket in a boiler 4 ft. 6 ins. diameter, which exploded at Dudley in 1864 after having been at work six weeks without cleaning, is shown in the transverse section, Fig. 37, Plate 50. In this case the scurf had filled up the circle of the boiler to a depth of 3 inches at the bottom, as shown in the drawing, and was of a very hard description; and the boiler plate was bent out in a gradual curve, and thinned out to about 1-16th inch, the original thickness being $\frac{1}{4}$ inch.

The whole bottom of a boiler is sometimes injured and the plates buckled and the seams sprung from the accumulation of mud. One case may be mentioned where the water was very full of mud, and the boilers were worked day and night during the week, but stopped for several hours on Sunday, during which time the deposit of mud was so thick that it did not get thoroughly disengaged again from the bottom when the boiler was set to work, but hardened into a mass. Although many of these pockets and injuries to the plates may occur without serious damage, they sometimes cause that first rent which destroys the equilibrium of the structure and leads to explosion. Some of the specimens of scurf exhibited to the meeting show that their thickness is made up of small chips carelessly left after cleaning or fallen from the sides of the boiler, as seen in Fig. 36, Plate 50; or from cotton waste or other matter left in the boiler and forming a nucleus for the scurf to accumulate upon. Other specimens show that foreign matter must have been put into the boiler to stop leaking.

Accumulations of scurf in the feed pipes at the point of entrance into the boiler have also caused explosion by stopping the supply of water. The same result is caused by the freezing of the water in the pipes which are exposed; and each winter one or two boilers are injured or exploded from this cause, especially small household boilers placed behind kitchen grates. Scurf cannot be considered so great an evil as corrosion, since it can be removed; and if this is done in time, the boiler is restored to its original condition.

The advantage of a pure water which does not deposit scurf is so great for the supply of boilers that it is always worth while to go to considerable expense for obtaining it; or to take some steps for purifying the feed water as much as possible. If it is only mud mechanically suspended, which would deposit by gravity on the bottom of the boiler, frequent use should be made of the blow-off apparatus. If the impurity is light enough to be carried to the surface in the form of scum, the blow-off apparatus should discharge from the surface of the water as well as from the bottom. If the impurity is chemically suspended in the water, some one of the many substances which form the refuse from various manufactures and which may contain suitable ingredients should be used to counteract the effect of the impurity. Common soda will answer the purpose perhaps better than anything else. It must not be forgotten however that the blow-off apparatus must afterwards be used more frequently, to rid the boiler of the foreign matter, or the mischief will be increased. In marine boilers constant attention is necessary to get rid of the saline deposit; and in stationary boilers using impure water an equally systematic attention is needed to get rid of the earthy deposit.

Perhaps no cause of explosion is oftener mentioned than shortness of water, and this is not unfrequently coupled with turning on the feed suddenly into an overheated boiler. Many explosions have been attributed to this cause, when closer investigation would have revealed some far more probable reason. For instance, shortness of water was stated as the cause of the explosion at Abercarn in 1865 of a single-tube boiler with a very large flue tube, which collapsed upwards from the bottom. The top of the tube and the sides of the shell had not the slightest mark of overheating, although exposed to the flame of three furnaces, one of which worked through the tube and the others on each side of the shell. In this case the cause of explosion was clearly the weakness of the tube, and not shortness of water. It is erroneous to suppose that if a boiler runs dry, or if the feed is turned into a red-hot boiler, there must necessarily be an explosion. If a boiler unconnected with any other

runs rapidly empty, from the breaking of the blow-off pipe or any such cause, it will simply get red-hot and sink out of shape upon the fire, as may often be seen; but no explosion would happen. If the water only falls gradually, as it would if the feed were turned off and evaporation continued, the parts exposed to the fire would get overheated as the water left them. If the subsidence of the water were very slow, those parts might get red-hot, and so much softened and weakened as to be incapable of bearing the pressure, when an explosion would take place, as at Smethwick in the present year, where the flues were set above the water line, as shown in Fig. 26, Plate 47.

If however the water were turned on again before the overheating had gone so far, and the feed pipe were as usual carried down to nearly the bottom of the boiler, the water would gradually creep up the heated sides and cool the plates, the heat of which would not be sufficient to cause greater evaporation than the ordinary safety valves would carry off. The danger would not arise so much from the excess of steam generated by the heat accumulated in the heated plates of the boiler, as from the injury and strain that would be caused to the plates by the undue expansion and sudden contraction, especially as this action would take place on only a portion of the boiler. A singular case bearing on this point may be mentioned. A four-furnace upright boiler, like that shown in Fig. 74, Plate 55, happened to run so nearly empty, through the accidental sticking of the self-acting feed apparatus, that the level of the water sank to the top of the hemispherical end forming the bottom of the boiler. The feed apparatus then became released of itself, and the feed being turned full on, the water gradually rose until the whole occurrence was only discovered by the leaking at the seams that had been sprung, which caused so much steam in the flues as to stop the working of the furnaces. The overheating had been sufficient to buckle the plates, and in one place a rupture had almost commenced; but there was no explosion. By way of direct experiment upon this point, boilers have been purposely made red-hot and then filled with cold water, without causing explosion.

It has been supposed that boilers sometimes explode from overheating without the water level being below the usual point, or without the accumulation of scurf previously alluded to, but simply by the rapidity of the evaporation from an intensely heated surface causing such a continuous current of steam as to prevent the proper contact of the water with the heated plate. Such has been the cause assigned for the explosion of a three-furnace upright boiler at Birmingham in 1865, shown in Fig. 20, Plate 47. A piece of plate about 3 ft. by $1\frac{1}{2}$ ft. was blown out of the side, at a place where an enormous flame impinged continually. The plates had first bulged out, and then given way in the centre of the bulge, each edge being doubled back and broken off. There was no positive evidence as to the water supply; but the crown of the centre tube, which was much above the bottom of the part blown out, remained uninjured.

A somewhat similar case was that of a large horizontal boiler at Kidderminster, the tube of which collapsed in 1865, as shown in Fig. 21, Plate 47. It was heated by four furnaces, one of which worked into the tube, one under the bottom, and one on each side; and all the furnaces worked into the same end of the boiler. The tube was found to have partially collapsed at that end, and the top had dropped 11 inches. This was repaired in the first instance, but was afterwards again found injured by overheating, although not so seriously. It is very probable that the extremely rapid ebullition from the sides and bottom, from which the steam had to pass up the narrow space between the tube and the shell, produced such a foaming that very little solid water could reach the top of the tube where it was exposed to extreme heat.

Many explosions have been attributed to deterioration of the iron through long use, as in an explosion at Durham in 1864, and another at Haswell near Sunderland in 1865, where the boilers had worked constantly for 25 and 30 years respectively. When an explosion arises from the failure of a plate which has not been properly welded in rolling, there is no question that it was unsound when put in, and escaped notice; but when the plate that fails is found to be brittle and of bad iron, the fault is rather attributed to the effect of

working than to original bad quality. Of course this is not always the case, as the injury done to plates by overheating has been already explained. Pieces of plate have in some cases been erroneously pronounced to be deteriorated by work, which have been taken from situations in the boilers where they were not exposed to any action of fire that could cause overheating; and therefore in reality the injury could only have taken place when the boiler was being made, by burning the iron in bending it to the required shape. A frequent cause of fatal injury to boilers is injudicious repair, whereby the crossing of the seams is destroyed, as in the explosion at Wolverhampton in 1865, previously referred to and shown in Fig. 8, Plate 44. Moreover the edges of the old plates, already tried by the first rivetting and the subsequent cutting out of the rivets, are frequently strained again by the use of the drift to draw them up to the strong new plates; and many a seam rip is thus started which ultimately causes explosion.

Many explosions have been caused by the want of proper apparatus for enabling the attendant to tell the height of the water and the pressure of the steam, and also by the want of sufficient apparatus for supply of feed water and escape of steam, or by the failure of one or other of these; but such explosions can only be referred to generally in the present paper. The mountings on a boiler are usually so open to observation, and the importance of having them good and efficient is so universally acknowledged, that much remark is not needed. Mention has already been made of the sticking of self-acting feed apparatus as a cause of mischief, and similar failures of floats and gauges have constantly happened; but this should by no means be considered to condemn self-acting apparatus, either for assisting in the steadiness of working, or for giving warning of danger. The apparatus however should be relied on for assistance only; and an attendant cannot be called careful who leaves a boiler dependent on such apparatus without watching. The self-acting principle has been seen by the writer applied in a novel and useful way in a recording pressure gauge, which proved the more interesting as it had shown the actual pressure of steam at the time of the explosion of one of the boilers with which it was connected.

Among the numerous boiler explosions that have been attributed to over-pressure through deficient arrangements for escape of steam, in many cases the safety valves have been placed on the steam pipes in such a manner that the communication with them was cut off whenever the steam stop-valve was shut, which is just the time when the safety valves are most wanted. Safety valves are too often found needlessly overweighted; and it is believed that many boilers are constantly worked with safety valves so imprudently arranged and weighted that they could not carry off all the steam the boilers would generate without a very great increase of pressure.

It is concluded that enough has now been said to show that boiler explosions do not arise from mysterious causes, but generally from some defect which could have been remedied if it had been known to exist. It only remains therefore to consider what is the most ready and efficient way to discover the true condition of a boiler. It has been maintained that this end is best accomplished by what is called the hydraulic test, in which a pressure of water is maintained in the boiler for a given time at a certain excess above the working pressure. This test is undoubtedly useful so far as it goes, and is perhaps the only one that can be applied to boilers with small internal spaces, such as locomotive boilers, not admitting of personal inspection over the whole of the interior; and it is also admirable for testing the workmanship of a new boiler. But on the other hand the conditions of a boiler at work are so different from those which exist during the hydraulic test, that this alone cannot be depended on; for old boilers have been known to stand this test to double their working pressure without apparent injury, although known to be dangerously corroded. The difficulty also of seeing or measuring the effect of the hydraulic test upon large boilers set in elaborate brickwork is so great that little practical benefit has resulted in many cases.

It is believed by the writer that the surest way to ascertain the true condition of a boiler is to examine it at frequent intervals in every part, both inside and outside; and as this can only be done when both the boilers and the flues can be readily entered, it is

specially important that facility for examination should be made a consideration in selecting a construction of boiler. Permanent safety should be considered as an element of economy, in addition to its still higher importance in reference to the preservation of life.

Mr. MARTEN exhibited a large collection of specimens of corroded and fractured plates from boilers that had exploded, together with models showing the construction of some of the exploded boilers and the results of their explosion. A set of elastic models of different constructions of boilers were also shown, by means of which the effect of over-pressure of steam in altering the shape of the boiler and thereby leading to explosion was clearly illustrated.

Mr. W. FAIRBAIRN fully concurred in the views advanced in the paper that had been read, as to the importance of periodical inspection as a means of preventing steam boiler explosions, and he considered that was the only way in which safety could be effectually ensured. In the case of the Manchester Boiler Association, with which he had been connected from its formation ten years ago, the practice referred to in the paper of careful inspection had been carried out from the commencement, and also that of collecting records of every particular connected with boiler explosions that occurred within the cognizance of the Association. During the ten years of its operations, only four explosions had occurred of boilers inspected by the Association, causing the loss of three lives; and this exemption from accident was entirely due, he believed, to the periodical inspection of every boiler once in every three months; for during the same ten years the explosions of boilers not inspected by the Association had caused the deaths of 500 or 600 persons, and serious injury to nearly double that number, making an average of 5 persons killed per month.

Having witnessed the gradual increase of steam pressure in stationary boilers during the past thirty years, from the original 7 lbs. pressure in the old Boulton and Watt boilers up to the present pressures of from 40 lbs. to 70 lbs. and 80 lbs. in many factory engines, he was strongly of opinion that there were certain circumstances connected with the employment of these higher pressures of steam which were not yet fully appreciated and practically attended to. This appeared to be particularly the case in reference to the remarkable circumstance of grooving that was supposed to be produced by oxidation along the edges of the joints in boilers working with the higher pressures, so that the metal of the plates became eaten away along the joints until the thickness was frequently reduced in some places to less than 1-8th or 1-16th inch; and in locomotive boilers working at still higher pressures this grooving action of the corrosion took place with still greater rapidity. The effect was probably produced by causes both chemical and mechanical, the former arising from the water with which the boiler was fed, and the latter from the construction of the boiler itself and the strains to which it was subjected by alternate expansion and contraction in working.

Another fruitful source of explosion was the collapse of internal tubes, both in single-flue or Cornish boilers and in double-flue or Lancashire boilers; and he believed almost as many explosions took place from the collapse of tubes as from the tearing of the outer shell of the boiler. He did not know however of any stationary boiler that was simpler in construction than the double-flue boiler, which was now in general use throughout the country, having originated with himself more than twenty years ago. But it was most important to bear in mind, in the case of internal tubes or flues, that the strength of a tube to resist collapse by external pressure varied inversely as its length; so that if a tube of 30 feet length collapsed under an external pressure of 100 lbs. per square inch, a rigid hoop put round it at the middle of its length would double its power of resistance and render 200 lbs. necessary to effect collapse. Several explosions of Cornish boilers by collapse of the internal flue had lately taken place, and he was surprised

that so simple a remedy had not been applied, as he believed the use of stiffening hoops round the internal tubes was now generally adopted in the Lancashire district, and this plan was particularly important in boilers having large and long tubes of 35 to 40 feet length and upwards. The internal flues had also been strengthened by the addition of small transverse tubes extending across the flue from top to bottom; but though the heating surface was thereby increased, so that more steam was generated, he thought there was no cheaper and better construction in the long run than the simple two-flue boiler. He hoped those principles of construction would become generally adopted that would admit of greatly increased pressures of steam being employed, with reasonable certainty of freedom from the lamentable results which followed in the train of boiler explosions.

Colonel KENNEDY considered they were greatly indebted to the author of the paper for the laborious attention he had given to the subject, and the very valuable information he had collected in reference to the causes of explosion in stationary boilers, which he had no doubt would be the means of directing attention also in other quarters to the explosions of locomotive and marine boilers. From the explanations given in the paper respecting the various causes of explosion, it was clear that much of the injury and loss of life which had hitherto been occasioned by boiler explosions might in future be prevented by careful inspection of steam boilers; and the obscurity in which the causes of so many explosions had been enveloped might henceforth be dispelled by proper examination, and the real causes of such accidents might in almost every instance be elucidated.

Mr. F. J. BRAMWELL remarked that it would appear, from the comments made in the paper upon the different descriptions of stationary boilers which had been noticed, that there was not any one kind of boiler which was considered entirely satisfactory; and from the several considerations that had been advanced in reference to the constructions of boilers it appeared that, so far as any preference was entertained, it was in favour of the plain cylindrical boiler with hemispherical ends, fired underneath, and fixed so as to

allow of complete examination of its entire surface at any time, and not having any covering on the top to prevent loss of heat by exposure. This seemed by no means a satisfactory result to arrive at, as he believed such boilers must always be wasteful in consumption of fuel, and liable to injury at the bottom by deposit of scurf upon the plates immediately over the fire. His own opinion was much more in favour of the Lancashire or double-flue boiler, which was perhaps in most general use for manufactories; for there was a greater amount of heat obtained with the same consumption of fuel from the internal fire situated inside the flues, as contrasted with an external fire playing upon the shell of the boiler: moreover the deposit could accumulate in the comparatively cool space below the flues without causing injury to the bottom of the boiler from overheating. There was also a fair amount of water space and steam room in this boiler, to serve as a reservoir for preventing any very sudden fluctuations in the steam pressure in case of negligent firing; and when the flues were properly stayed by external strengthening rings, there need be no reason for fearing explosion by collapse of the flues. Allusion had been made in the paper to boilers holding only a small amount of water, so as to lessen the disastrous consequences of an explosion and prevent any serious damage being done by such an accident; and some boilers of that class had doubtless proved completely satisfactory in this respect and highly successful in rapid generation of steam, particularly with the improved arrangements devised for ensuring efficient circulation of the water. He fully concurred however in the remarks made in the paper respecting these boilers, that on the very account of the small quantity of water contained in them there was constant danger of injury to the boilers themselves from any negligence in the firing or any irregularity in the feed. Moreover in boilers producing so very rapid a generation of steam in proportion to their contents he thought the statements that were frequently made as to the rate of evaporation of the water should be received with some doubt, when the evaporation was ascertained only by means of a water meter attached to the feed pipe; for he believed in many cases where a very high evaporation was supposed to be obtained, if the

exhaust steam from the engine were passed into a condenser, it would be found that the amount of water deposited in the condenser was much more than that due to the steam employed in the engine, showing that a considerable quantity of water must have been carried off from the boiler mixed with the steam, owing to the violent ebullition of the water in the boiler. In these cases therefore he considered the only correct way of arriving at the actual evaporative power of the boiler was by the employment of a condenser in connection with the engine; by which means not only could the amount of water brought over be ascertained, but the heat given out could also be measured, and thus the quantity really evaporated and that carried over by priming could be separately arrived at.

With regard to the covering of stationary boilers, he was surprised that the use of sand for the purpose had not been spoken of more favourably in the paper, as he had himself employed it constantly for covering boilers and had found it a very satisfactory means of protecting them. The sand was itself a very good non-conductor of heat, and it was cheap, and easy to be removed with a shovel at any time for examining the boiler plates, and in this respect decidedly superior to more costly coverings which could not be readily removed. Any droppings of water upon the sand covering became absorbed by it, as by a sponge, without penetrating so far as to reach the boiler plates, if a proper thickness of sand were used; and the moisture was afterwards evaporated by the heat from the boiler. On these accounts he had been led to consider sand the most advantageous material that could be employed for covering stationary boilers. The feeding of boilers ought no longer to present any difficulty; for if the Giffard's injector were applied to every boiler or set of boilers, in addition to the present feed pumps, the regulation of the feed in stationary boilers would always be absolutely under control, and could be adjusted to correspond exactly with the quantity of steam required.

Mr. H. MAUDSLAY remarked that the voluminous and authentic records contained in the paper formed a most valuable contribution to the Proceedings of the Institution, and the careful manner in

which the information had been compiled and illustrated further enhanced its value; and they were greatly indebted to the author for having prepared the paper. A very useful summary had been given at the commencement of the paper, not only of the number of explosions that had occurred from the different causes which led to such accidents, but also of the number of explosions that had taken place with the different constructions of boilers in general use; and he had no doubt that the continuance of such a system of classification would lead to beneficial results in the prevention of explosions for the future. As the subject of the paper was the explosions of boilers, it was of course unavoidable that all the instances adduced as illustrations in the paper presented some unsatisfactory features, through the existence of which a failure of the boiler had either actually taken place, or might be expected to occur unless effectually guarded against by proper inspection; and it would remain for the balance of advantages or disadvantages attending any particular construction of boiler to be determined by the special circumstances of the situation and working in the particular case under consideration.

Mr. W. RICHARDSON observed that among the specimens exhibited of fractured boiler plates he noticed one which appeared to be taken from the bottom of the shell of a cylindrical boiler, where the fracture had run along one of the transverse circular seams through the line of the rivet holes; and he enquired what was supposed to have been the cause of the rent in that case, as the iron of the plates appeared to be sound and of good quality.

Mr. MARTEN replied that the fractured plate referred to was from the bottom of one of the very long plain cylindrical boilers constructed for being heated by the waste gas from the blast furnace, which had ruptured at an ironworks in the North of England; and he believed the rent had been caused in the manner explained in the paper, through the bottom of the boiler being expanded by the heat while the top was kept cool by exposure to the air, the amount of the strain being aggravated by the great length of the boiler.

Mr. W. RICHARDSON thought that could not be the correct explanation of the fracture in this case, as the expansion of the

bottom of the boiler would put a strain of compression upon the plates in the bottom, and the rent must of course have been occasioned by tension. He thought the cause was one which was often met with, particularly in plain cylindrical boilers, namely an injudicious mode of supplying the feed, the cold feed water being delivered into the boiler in an undivided stream near the bottom, or falling direct to the bottom by its greater specific gravity, whereby the boiler bottom was suddenly cooled at one part and caused to contract violently, while the rest of the shell remained heated and expanded; then the strain produced by the contraction would of course run to the weakest part of the boiler bottom, and a fracture would ultimately be produced by the repeated action of the strain at each time of turning on the feed again after it had been shut off for an interval. In order to obviate this difficulty he considered the feed water ought always to be either heated before entering the boiler, or circulated through pipes inside the boiler itself, so as to be made sufficiently hot before being allowed to mix with the water in the boiler, in order to prevent any injurious effects from difference of temperature.

Mr. W. WALLER said that he was personally acquainted with the case of the fractured plate exhibited, and the feed water had been heated before entering the boiler; and therefore he thought a sufficient explanation appeared to be that the boiler had on some occasions been emptied by blowing off, while the flues surrounding it continued nearly red-hot, so that the whole boiler shell became very much overheated; and then the sudden cooling of the bottom by the free admission of cold air would have produced the severe strain of contraction which ultimately led to the rent. In some instances of similar rents in the bottoms of plain cylindrical boilers, in which the shell was made of Cleveland plates, but the bottom exposed to the fire of Low Moor plates, the cause could not be traced to any defect in the plates or the rivetting; and the idea was then suggested that it might be due to a different rate of expansion in the two qualities of plates used in the construction of the boilers. In order to ascertain the actual difference of expansion, two strips of plate, which he exhibited, one of Low Moor iron and the other

of Cleveland iron, each 47 inches long by 3¾ inches wide and ⅝ inch thick, were rivetted together side by side at one end; and on then heating them together to a black red heat it was found that the Low Moor bar had expanded fully 1-16th inch less in length than the other. In one of the cylindrical boilers of 80 feet length this extent of difference would amount to as much as 1¼ inch, the consequence of which must be a severe tensile strain on the bottom of the boiler; and he had seen cases of as many as three or four seams ripped in the length of the boiler bottom, where the bottom had been made of Low Moor plates while the rest of the shell was of common iron.

Mr. L. E. FLETCHER, Engineer of the Manchester Association for the prevention of steam boiler explosions, was sure it must have been no easy matter to collect all the details and arrange such a mass of information as was given in the paper that had been read; and it was clear that the subject of stationary boilers alone afforded ample material for a long paper, without going into the question of locomotive and marine boilers. From his own experience in investigating the causes of boiler explosions for some years past he was convinced that a great deal of unnecessary mystery and uncertainty had been attached to the subject, while in truth there was no mystery whatever connected with it; and he thought no progress would be made in the prevention of explosions until it was accepted as a principle that there was nothing incomprehensible in connection with such catastrophes. The whole range of causes might be summed up in the single word "neglect:" either disregard of some mechanical principles in the original construction of the boiler, or want of proper attention in its subsequent working to ensure the conditions requisite for safety. Explosions from collapse were due to neglect in first construction; and those from shortness of water, excessive pressure of steam, or wasting of the boiler plates by corrosion, to neglect in subsequent management.

The plain cylindrical egg-ended boiler, though apparently advantageous in construction before being put to work, he had found practically a very dangerous form, as it was so unmanageable in working that scarcely any amount of attention or inspection

could keep it safe. The fractured plate exhibited from the bottom of a plain cylindrical boiler, with the rent following one of the transverse circular rows of rivets, illustrated the way in which such boilers frequently failed; and he thought the general cause of these failures was very simple, and was not sufficiently apprehended. It was evident that a rent in that situation could not arise from expansion of the boiler bottom, but must be produced by contraction, and he believed that contraction was continually occurring in ordinary working, from the firedoor being opened for firing; and then, the bottom of the boiler being very hot in consequence of the external firing, the rush of cold air every time the door was opened caused a sudden cooling and contraction of the bottom plates, the constant repetition of which frequently produced a rent across the bottom, exactly as in the specimen exhibited. On this account he did not think a boiler of that class could be kept safe for working, even when the feed water was heated; and with cold feed water the injury to the boiler bottom was of course still more rapid, as the cooling effect of the feed caused the bottom to contract and to be in tension from the sides of the boiler remaining expanded by heat. In all constructions of boilers the most effectual remedy for the evils attending cold feed water was to heat the feed before it entered the boiler, and to disperse it gently over a large area instead of delivering it all in at one spot. A seam-rent along a line of rivet holes, such as was seen in the specimen exhibited, was also sometimes caused by bad workmanship in the construction of the boiler, the rivet holes not being made to correspond with sufficient accuracy in the two plates, so that the rivets could not be put in fairly parallel and the holes had to be worked with a drift, whereby the iron was severely strained and small cracks were liable to be started at the rivet holes.

The upright boilers heated by puddling furnaces in ironworks, surrounded with brickwork, and placed in the busiest part of the works with numbers of men around, seemed as if specially contrived for doing as much injury as possible in case of an explosion. When one of these boilers exploded, it sent the brickwork flying like grape shot in every direction; and by the explosion of such a boiler he had known as many as twenty-five persons killed on the spot, while

the havoc produced was fearful. These boilers, like the plain cylindrical boilers, were indeed quite unmanageable in practice. The flames from the furnaces impinged direct upon the boiler plates; for although there might be a screen of brickwork at the bottom in the first instance, to protect the plates from being overheated, this was liable to fall away without being noticed, or even if its defective condition was known there was seldom time to stop the furnaces for repairing it; and the flames were allowed to play on the plates with full force, until an explosion was the result of the consequent injury to the plates.

Explosions arising from the collapse of internal flues could be entirely prevented by the addition of the external strengthening hoops that had been already referred to; while wasting of the boiler plates by corrosion could be detected by careful inspection in time to avert the danger. In connection however with explosions arising from both these causes it too frequently happened that the blame was laid upon the stoker, when he was only the victim and not the cause of the explosion. An instance of this sort was afforded by the explosion that occurred in 1865 at Abercarn in South Wales, which was stated to have been caused by shortness of water, and the blame was laid upon the engineman, whom however he believed to be quite innocent in the matter; for it was certain that the explosion, which arose through the collapse of the internal flue of the boiler, was simply due to its weakness, since the flue was not strengthened as it should have been with any external hoops, though as much as 4 feet in diameter, oval in construction, and worked at a pressure of 57 lbs. per square inch; while the plates were wasted by corrosion, and improperly repaired with patches bolted on instead of rivetted. Such an example as this, where the simple weakness of the construction of the boiler had been the cause of the explosion, was sufficient to show the importance of ascertaining the real source of mischief in every instance, and not allowing the matter to be mystified by any circumstances of doubtful reality.

Of all the stationary boilers that came under his inspection he had found the two-flued or Lancashire boiler internally fired was

the safest. Although there must of course be a contest between the internal flues and the shell of this boiler from their different amounts of expansion, yet this was now fully understood, and successfully met by a proper mode of construction. It had been a difficulty of many years' standing, but was now fairly overcome and provided for. The proper way to construct all internal flues he considered was to bend the plates to a perfectly true circle, and weld the longitudinal joints instead of rivetting them, so as to avoid destroying the truth of the circle by a lap joint; and then either to add strengthening rings of T iron for securing the tube against collapse, or to flange the plates outwards at the transverse circular seams. By also taking care to secure elasticity in the end plates, and to leave sufficient water space between the flues and the shell of the boiler, the contest between them from difference of expansion was so far diminished as to be practically harmless, especially when the length of the boiler did not exceed 28 feet; and the boiler should be so set that the flame passed first under the bottom, after leaving the furnace tube, and last along the sides. With this mode of construction the thickness of the plates forming the flues might safely be reduced from the present $\frac{1}{2}$ inch or 7-16ths inch to 3-8ths inch, or even to $\frac{1}{4}$ inch if steel plates were employed for the purpose; by this means the flues would be rendered lighter and less rigid in the longitudinal direction, and the thinner plates would be less liable to become overheated, in consequence of their conducting the heat more rapidly to the water. Lancashire boilers constructed in this manner could be safely guaranteed from year to year to continue in regular working without risk of explosion; whilst the plain cylindrical boilers and other boilers fired externally might be considered liable to risk from day to day.

The important conclusion therefore derived from the inspection of boilers in working and the investigation of all cases of explosion was that boiler explosions were not unaccountable, but originated always in some simple cause; and their prevention was not beyond the reach of engineering science, a periodical and careful inspection forming an essential condition for attaining the desired safety.

Mr. C. J. GALLOWAY referred to the plan which had been mentioned of strengthening the internal flues of boilers by transverse conical tubes, placed vertically or obliquely across the flues, so as to form a communication between the water above and below the flues. This construction he thought had some advantages over the external T iron strengthening rings, as the transverse tubes not only strengthened the flues against collapse, but also greatly facilitated the circulation of the water and thus produced a greater equality of temperature throughout the boiler, whereby the contest arising from the unequal expansion of the flues and shell was mitigated. At the same time the additional heating surface afforded by the conical tubes increased the evaporative power of the boiler; and the tubes had been found quite satisfactory in working.

Mr. L. OLRICK remarked that the very interesting and useful paper which had been read would be fully appreciated by all engineers, particularly as it contained a number of hints based upon the practical experience acquired by the author from an extensive acquaintance with steam boilers. One description of stationary boiler which had been alluded to in the paper, but had not come much under the author's practical notice, was that having a cluster of small vertical tubes suspended over the fire, for the purpose of obtaining the greatest possible amount of heating surface immediately over the fire. A similar construction had been tried some years ago, in which a smaller internal tube was inserted down the centre of each of the heating tubes for the purpose of ensuring the requisite circulation of the water, the cooler water from the body of the boiler passing down through the central tube, while the heated water and steam rose through the annular space between the two tubes. It was found however that, in consequence of the very large extent of heating surface exposed by the tubes in proportion to the quantity of water contained in them, the current of steam and water issuing from the top of the annular space was so violent as to interfere with the downward stream of cooler water through the central tube. This was now obviated by making the central tube trumpet-mouthed at the top end, so as to divert the ascending current of steam and water, and ensure an uninterrupted entrance

of the cooler water into the central tube, whereby a constant supply of water was maintained over the whole of the heating surface of the boiler. The result of this arrangement was that the boiler was exceedingly efficient in rapid evaporation, and in the steam fire-engines provided with these boilers steam was got up from water at 40° or 50° Fahr. to a pressure of 100 lbs. in $7\frac{1}{2}$ minutes. The objection that had been urged against the use of these boilers for ordinary stationary purposes was that, on account of the very small quantity of water contained in them in proportion to the heating surface, they could not be worked with so much safety, as any shortness of water in the tubes over the fire would cause them to become burnt, and an explosion would ensue. This difficulty however was readily obviated by employing a much larger water space when the boiler was used as an ordinary stationary boiler, and it then worked just as well as other boilers containing a large reservoir of water. One of these boilers was now used at the St. Katharine's Dock, London, in connection with Sir Wm. Armstrong's hydraulic machinery; it occupied a ground space of only $6\frac{3}{4}$ feet diameter and was about 12 feet high, and it evaporated 60 cubic feet of water per hour, which he believed was more work than any other boiler occupying the same space could do. In this case the boiler was fed with the water from the dock, which was exceedingly dirty and partially salt, and it had been doubtful whether the boiler would keep clean in working. It was found however that all the dirt was collected with the scale at the bottom of the water jacket provided for the purpose, which surrounded the firebox. Such a boiler might be pronounced practically safe from explosion, and no explosion had yet occurred with any of the boilers on that construction. An instance had occurred however about twelve months ago with another of these boilers, employed at Messrs. Siebe's ice-machine manufactory in London, where an explosion or collapse of the internal flue must inevitably have taken place had the boiler been one of the Cornish type. In this case the height of the water in the gauge-glass had been accidentally mistaken, the glass being thought to be full of water when it was really empty; and the consequence was that the water level in the boiler

became about 12 inches lower than the tubeplate, when the tubes over the fire, which were made with their bottoms soldered in, had the bottoms of some of them burnt out, and thus acted as safety plugs, causing the fire to be put out and thereby preventing further injury. This construction of boiler he therefore believed to be not only as safe but even safer than the ordinary Cornish or Lancashire boilers.

For the purpose of preventing over-pressure of steam he had endeavoured to increase the readiness of blowing off with the ordinary safety valves by increasing the inclination of the face of the valve seating to the valve spindle from the ordinary slope of 45° to 60°; but he had found the valves had a great tendency to stick, and in some instances the pressure in the boiler had risen to as much as 100 lbs. per square inch when the valve had been set to blow off at 60 lbs. He had also tried flat-faced safety valves having an annular bearing face from 1-16th to 1-8th inch wide, which was found to produce an improvement in preventing so great an excess of pressure in blowing off. The improved safety valve of Mr. Naylor (see Proceedings Inst. M. E. 1865 page 220) he had found to be very efficient in preventing over-pressure of steam; and on a boiler evaporating 60 cubic feet of water per hour one of these valves of 2 inches diameter had kept the steam pressure from rising under any circumstances more than 1 lb. above the limit of 70 lbs. at which the valve was set to blow off.

For testing boilers he thought a combination should be adopted of the hydraulic test and the steam test; and for this purpose he had the fire lighted and thus filled the boiler with boiling water at the time of applying the testing pressure by the pumps, whereby the condition of the boiler under the test was made to correspond more nearly with the circumstances of actual working.

Mr. MARTEN remarked that the particulars which had just been given of the working of one of the water-tube boilers having a cluster of small tubes suspended over the fire went to confirm the observations made in the paper respecting the inconveniences attending the practical working of these boilers for ordinary stationary purposes; the water space being so small in proportion

to the very high evaporating power that the boiler could not be left unattended even for a few minutes without risk of the supply of steam becoming deficient and injury occurring to the boiler itself. Of course if the water space was increased to the same extent as in ordinary Cornish or Lancashire boilers, the rapidity of evaporation would be proportionately reduced, and would no longer constitute as at present the principal feature of these water-tube boilers. With regard to the different constructions of boilers, he had to remark that it had not come within the scope of the paper, as a record and analysis of boiler explosions, to recommend any particular construction as the best for general stationary purposes; but the preference had certainly not been given to the plain cylindrical egg-ended boiler, the disadvantages of which had been pointed out in the paper; while at the same time the double-flue or Lancashire boiler had not been passed over without a strong commendation on account of its many important practical advantages.

In reference to the covering of boilers, it had not been suggested in the paper that they should be left uncovered, but a roof had been strongly recommended as the very best covering. As regarded the use of sand as a covering, it would be remembered that at a former meeting of the Institution sand had been recommended for the purpose by Mr. Henry Marten (see Proceedings Inst. M. E. 1856 page 8); but subsequent experience had not confirmed the favourable opinion then expressed, and some boilers that had been covered with sand in consequence of the remarks then made had since been found so much injured by external corrosion that their tops had required renewal after only five years' working. Similar corrosion had taken place in a set of boilers covered with ashes, the tops of which had required renewal after only six years' working. Other instances of the extent of the corrosion both with sand and with ashes for the covering were shown in the specimens exhibited (Figs. 31 to 34, Plate 49). The internal channelling along the seams of a boiler caused considerable trouble, and he had known a stationary boiler grooved along every seam below the water level until more than half the thickness of the metal was gone, just as if a groove had been cut out of the plates with a gouge.

No reference had been made in the paper to locomotive and marine boilers, because his own experience had been principally confined to stationary steam boilers.

The PRESIDENT moved a vote of thanks to Mr. Marten, which was passed, for his valuable paper, and the great amount of labour he had bestowed upon its preparation.

The following paper was then read :—

DESCRIPTION OF THE REMOVING AND REPLACING OF THE IRON COLUMNS IN A COTTON MILL.

By Mr. WILLIAM FAIRBAIRN, of Manchester.

The improvements that have been effected in the machinery for spinning cotton have given rise to new conditions, new buildings, and new appliances, to meet the numerous changes that have taken place. The machinery for carding, roving, and spinning, has been renewed three different times within a period of less than sixty years, the old machines having been three times removed to give place to others of a more improved construction. The old narrow buildings of former days have consequently proved unequal to present wants, and it has been necessary either to alter the old mills to suit the new machinery, or to build new ones. The latter plan was occasionally preferred; but more frequently the spinning rooms of the old mills were altered so as to suit the new mules, which from their increased number of spindles had to be fixed in the longitudinal direction, instead of transversely as formerly.

Immediately after the invention of the mule by Crompton, or about the commencement of the present century, a cotton mill 45 feet in width was considered of proper dimensions for mules of 350 to 400 spindles. Two of these mules were looked upon for many years as the correct number for one man to work; and this might have been continued for a longer period, but for the invention of the self-acting mule by the late Mr. Roberts and others, which gave a new impetus to the spinning process; and in place of 400 spindles as formerly, the mules of the present day contain from 800 to 1000 spindles. This increase in the length of the mule required a corresponding increase of width in the mill; and hence arose the tower-like form of modern cotton factories, having as much as 90 to 100 feet and in some cases 120 feet width.

In the construction of modern mills no difficulty exists, as they are built to suit the machinery; whereas in adapting the old narrow buildings to the new mules it was necessary to remove the old mules and place the new ones in the opposite or longitudinal direction of the mill. In mills with wooden floors this was easily accomplished by removing one row of columns to admit a pair of mules in the middle; but in fire-proof buildings constructed with iron beams and brick arches the greatest possible care was necessary to be observed in effecting the desired alteration, as illustrated in the case forming the subject of the present paper, where 90 to 100 tons of arches and machinery had to be supported on two columns in each bay of a building eight stories high, the mill being kept working during the whole time the alterations were going on.

The objection to this operation on the part of the proprietors, Messrs. McConnel and Co., was that the columns could not be removed without cutting them, which might incur the danger of the whole of the floors above being "brought down by the run." Each column had in fact to be cut in two, taken entirely out, and new ones substituted at the required distances apart. As the particulars may be useful and interesting, the writer offers the following description of the process by which this object was successfully accomplished under his directions.

In Figs. 1 and 2, Plate 56, are shown longitudinal and transverse sections of the mill, which is eight stories high, and extends for a length of 160 feet along Union Street, Manchester, fronting the Rochdale Canal; it runs parallel with the canal as far as Murray Street, where it terminates with an angular wing 80 feet long. The width of the mill is 45 feet; and this was originally divided into three equal spans of 15 feet, as shown by the dotted lines in Fig. 2, by two rows of columns carrying the cast-iron beams which support the transverse brick arches forming the fire-proof floors. The distance of the columns apart from centre to centre in the longitudinal direction is 9 ft. 8 ins.; and as each mule requires nearly that space for drawing out its carriage, the original width of 15 feet between the pillars transversely was too small to

admit a pair of mules in the longitudinal direction down the middle of the room. It was therefore necessary to move one row of columns nearer to the side wall, in order to give space for the two centre mules to work, as shown at A in the transverse section, Fig. 2. The other mules next the side walls had quite sufficient room, with the addition of a passage B, which extended along the side wall the whole length of the mill.

In the process by which these alterations were effected the first consideration was how to support the ends of the middle beams and arches at C C, Fig. 3, Plate 57, during the process of removing the columns from under them; and also how to support the middle beam permanently after the columns had been removed. This could not be done simultaneously throughout the mill when at work, as it would have involved a very heavy expense to support the ends of all the middle beams at once, with their superincumbent weight of 90 tons of brick arches and machinery upon each. Moreover it was essential that only one pair of the old mules should be stopped at one time, and only during the operation of fixing the new columns at D D and cutting out the old ones at C C.

The first thing to be done therefore was to prepare the new columns with their projecting brackets of sufficient length to reach beyond the ends of the wall beams, so as to support the ends of the middle beams at C C after the old columns were removed. As it was impossible however to remove that part of the column which went through the beams, it was necessary first to fix the new columns under the wall beams at D, and subsequently to cut out the old ones progressively as the work advanced from one end of the room to the other. The brackets on the new columns were made to project to about the same extent on both sides; but as they could not be extended the whole length on the side next the original columns until the latter had been cut out and removed, the bracket intended for supporting the end of the middle beam was left 12 inches short, so as to leave sufficient space for attaching the apparatus for cutting out the old column; and a loose end was afterwards bolted on, as shown at E, Fig. 3, Plate 57, which was made to fit the stump end of the old column after the column had been neatly cut off and removed.

Before removing the old columns, it was requisite to fix the new ones and make all the floors secure from bottom to top. This would have been comparatively an easy task provided the new columns had gone down to the bottom for foundations; but that was impracticable, as the two bottom rooms which contained the preparation machinery were not to be disturbed: the six floors above, which contained the mules, being those only that required alteration. The base of the new line of columns was therefore supported from the room F above the ground floor, Fig. 2, so as not in any way to interfere with the machinery below. Strong hollow wrought-iron beams G were fixed immediately under the cast-iron wall beams in the room F, and upon these were raised the new lines of columns through six floors to the top of the mill. One end of each beam G was fixed in the wall, and the other on a casting at H, Fig. 3, which embraced the column and transmitted the weight of the superincumbent arches to those below.

The new columns having thus been fixed in their places, the next process was to put a temporary prop under the middle beam, to support the arch above and to give room for cutting out the column before the loose end of the bracket could be attached for the final support of the middle beam. In this way, working from the top story downwards, as shown in Fig. 3, the process of cutting out the columns was entirely free from risk; for instead of supporting the whole of the arches in two bays from top to bottom of the mill, only those of one floor had to be supported at one time. Thus in succession the entire line of the old columns was cut out and removed, and the whole of the floors of the six uppermost rooms were placed on new foundations.

The carrying out of this work was accomplished by Mr. Andrew Ker; and in order to save time and labour the apparatus shown in Figs. 4 and 5, Plate 58, was devised by him for the purpose of taking advantage of the shafts in motion for cutting out the columns with great rapidity and success. The apparatus itself consists of two cast-iron clips K embracing the column, and forming a table for supporting the spur wheel L, which revolves round the column and

carries the cutter J. The wheel is driven by the worm-shaft and pulley M, which receives motion from one of the driving shafts N, Fig. 3, in each room. The shank of the cutter is screwed to receive the ratchet-nut P, and by means of the finger Q the cutter receives the required advance equivalent to the thickness of the cut every time the ratchet passes the finger. The screwed shank of the cutter J is planed down flat on the top and bottom sides, as shown in Fig. 4, so as to hold the tool from turning in its socket.

By this means the column was quickly cut through at the top; and the width of the cut being sufficient to allow of the column being then canted enough for drawing the head from under the stump end cut off, the column was lifted out of the socket at bottom and removed. The loose end of the bracket having then been inserted with two strong bolts, as shown at E, Fig. 3, the end of the middle beam was thus supported with the same security as if the original column had never been disturbed.

Mr. FAIRBAIRN remarked that the operation of removing the columns as described in the paper had appeared rather hazardous at first, as it had to be done while 300 persons were at work in the mill, and the weight of the iron girders and brick arches forming the floors amounted to 90 tons altogether. The work had however been performed with great care, taking one floor at a time and proceeding from the top downwards; and he believed the building was quite as safe now as before the alteration.

The PRESIDENT moved a vote of thanks to Mr. Fairbairn for his paper, which was passed.

The following paper was then read :—

ON AN IMPROVED MODE OF MANUFACTURE OF STEEL TYRES.

By Mr. JOHN RAMSBOTTOM, of Crewe.

In designing the mode of manufacture of Steel Tyres forming the subject of the present paper, the object aimed at by the writer was to reduce the waste of material in the process to so small an amount as to leave its effect insignificant upon the cost of production, and upon the calculation of the weight of ingot required for producing a tyre of given dimensions. Another object was to reduce the time of manufacture, thereby reducing the proportionate cost of plant by turning out more work in the same time.

The ingots are made from Bessemer steel, cast into the moulds shown in Figs. 1 and 2, Plate 59. They are in the form of a cone, 22 inches diameter at the base and 22 inches height, the corners at the base being rounded off. The apex of the cone is cut off at 6 inches diameter, and forms the opening for filling the mould. This is the size of ingot for making a 5 feet tyre, as shown in Figs. 14 to 19, Plate 67. The mould is made of cast iron, in two parts, jointed round the bottom edge, and the upper part fits down flat upon the bottom within four snugs, and is held there by its own weight alone when casting. When the mould is filled, the top of the metal is covered with a thin plate A, and the neck is filled in with wet sand and cottered down in the usual way.

To prevent the cast-iron mould from cracking by unequal expansion whilst the steel is setting, in consequence of the bottom of the ingot being more rapidly cooled than the middle portion, the sides of the mould are made of the curved form shown in Fig. 1, changing in thickness from 4¼ inches thickness at the bottom to 5¼ inches in the middle, and thinning again to 2¼ inches at the neck.

The bottom is 4 inches thick in the centre, and is protected from cracking by a wrought-iron hoop B shrunk round the outer edge. The centre of the base of the mould is made of fireclay, by inserting a plug C into a tapered hole in the bottom, to prevent the cast-iron bottom from being injured and burnt away by the stream of melted steel when poured into the mould at the top. This fireclay plug is readily renewed when required, being made from the worn out tuyeres of the Bessemer converting vessel.

As soon as the ingot can be removed from the mould it is reheated and then hammered laterally and endways in the manner shown in Figs. 3 to 6, Plates 60 to 62. The hammering is done by the 10 ton horizontal duplex hammer shown in the drawings, the two hammer heads D and E weighing each 10 tons, and moving horizontally towards each other. The cone is first hammered laterally all round its lower edge, as shown in Figs. 3 and 5, the object being to consolidate the skin of the metal and prevent cracking during the subsequent processes. The ingot is supported during the hammering by a carriage F specially constructed for the purpose of allowing the ingot to be rotated whilst being hammered. This carriage is made of boiler plate, mounted upon a cast-iron base-plate G; and the base-plate rests upon the centre bearings J J below, upon which it has a slight rocking motion, allowing the ingot to be adjusted between the two hammer faces, so as to secure the uniform action of the hammers upon it. The hand-lever H H connected with the base-plate G is held by the attendant during working, for adjusting the position of the ingot between the hammer heads. In hammering the ingot laterally, the two wrought-iron swage blocks I I, Fig. 3, are attached to the hammer heads; and a small turntable K, Figs. 3 and 5, supports the ingot at the top of the carriage F, allowing it to be rotated horizontally between each blow, by means of a fork which lays hold of the ingot like a spanner. This turntable is carried on a vertical centre pin, dropped into a cast-iron socket; and it is lifted out when the side hammering of the cone is completed.

The ingot is then canted over on its side, and hammered in the direction of its axis, as shown in Figs. 4 and 6, until it is reduced to

9 inches height, as shown in Fig. 15. The hammer head D, which acts upon the apex of the cone during this process, is narrower than the other head, and has the effect of spreading out the narrow apex more effectually than would otherwise be the case. In this position the cone rests upon the four rollers L L and M M contained in the body of the carriage F. Two of these rollers M M, carrying the large end of the ingot, are 10 inches diameter by 9 inches length and 1 inch tapered, and remain fixed in position. The other two rollers L L are 9 inches diameter and $1\frac{1}{2}$ inch thick, and are carried in a cast-iron frame which slides vertically within wrought-iron guides, and is supported by a long wrought-iron wedge N, Figs. 5 and 6. This wedge, which is 7 feet 10 inches long, is driven home at the commencement of the hammering, and is gradually drawn out so as to lower the supporting rollers by degrees, and accommodate their height to the increasing diameter of the centre of the ingot during the hammering. The rate of withdrawing the wedge N is regulated by the attendant, who has thus complete facility for adjusting the ingot constantly to its true level between the two hammers with as great accuracy as if he were holding it by hand. The taper in the two fixed rollers M M, Fig. 4, allows for the slight increase in diameter of the base of the ingot, which advances downwards towards the small ends of the rollers as the hammering proceeds. The ingot is continually turned round upon these rollers during the hammering by means of ordinary pinch bars.

The bloom, which is now in the form of a flat disc 22 inches diameter and 9 inches thick, as shown in Fig. 15, Plate 67, has then a hole punched in the centre to form it into a ring, by the punching hammer shown in Figs. 7 to 10, Plates 63 and 64. This is a 5 ton vertical hammer, having a projecting cone O upon the hammer face, 17 inches length and 12 inches diameter at the base, with a rounded apex. This cone is of cast steel, in one piece with the hammer face P; and a hole is first punched in the centre of one side of the bloom extending nearly through its thickness. The bloom is then turned over upon the anvil, and the conical punch is driven through from

the other side, this process being repeated until the hole in the bloom is enlarged on both sides to the size of the base of the conical punch, as shown in Fig. 16. The flat hammer face P, which is prolonged on each side of the punch, as shown in Fig. 7, then acts upon the bloom, and hammers it down in thickness, the bloom being turned round horizontally between each blow. By this means the bloom is brought to 31 inches diameter and $5\frac{5}{8}$ inches thickness, with a centre hole 11 inches diameter in the middle, as shown in Fig. 17. The anvil block Q is made with a hole all down the centre, large enough to give clearance to the punch in its lowest position, as shown in Fig. 9; but in order to prevent the centre portion of the bloom from being driven down into this hole at the commencement of the work, the hole is at first contracted in size by a steel ring R, Figs. 8 and 10, dropped into a recess at the top. This ring is afterwards removed when the punching of the hole has been partly completed on one side of the bloom.

In order to afford facility for turning the bloom over quickly upon the anvil of the punching hammer, a swing frame S is employed having two centre screw pins, which seize the bloom a little below its centre of gravity. These screws are tightened up by hand for laying hold of the bloom, and after it has been turned over they are slackened back again, and the swing frame lies on the ground out of the way during the hammering. When in use the outer end of the swing frame is connected by a chain to the hammer head, as shown in Fig. 7, so that the frame and bloom are lifted by the hammer, and the bloom turns over by its own weight, thus requiring no crane. During the hammering the bloom is turned round horizontally upon the anvil by means of ordinary pinch bars.

The next operation is hammering out the bloom edgeways, in order to enlarge the centre hole, which is done upon the beck anvil shown in Figs. 11 to 13, Plates 65 and 66. The side of the anvil T is inclined at 20° to the vertical; and the beck iron U, which stands out at 81° to the side, projects 10 inches and is $11\frac{1}{2}$ inches diameter at the base. The bloom is rotated vertically between each blow of the hammer by means of a pinch bar V, Fig. 12, suspended by a

chain from the top of the hammer framing. After the hammering on the beck is finished, the bloom is laid flat on the top of the anvil and hammered all round, as shown in Fig. 13, whereby the slight increase of width produced by the spreading on the beck is hammered down to the final width of $5\frac{5}{8}$ inches, as shown in Fig. 18, Plate 67. After the completion of each process, any cracks which may appear on the surface of the metal are chipped out.

By this hammering the bloom is brought to 34 inches diameter, with the centre hole 19 inches diameter; and it is then finished in the circular rolling mill, the well-known ingenious invention of Mr. Rothwell Jackson, one of the Members of the Institution, which brings the bloom to the form and dimensions of the finished tyre, as shown in Fig. 19, by rolling it at the same time both outside and inside without altering the width. This machine completes the rolling of the bloom into a finished tyre at one heat, the time occupied being about $5\frac{1}{4}$ minutes in the rolling machine.

The whole of the above process for the manufacture of the tyre is effected in four heats after the original casting of the ingot, which is taken from the mould as soon as the metal has set, and is then reheated for the first time before being taken to the horizontal duplex hammer. The second heat is in preparation for the punching of the centre hole, after which the bloom is again reheated for the beck anvil; and the fourth heat is for the final rolling of the tyre in the circular rolling mill. When the arrangements are fully completed, it is expected that the number of heats will be reduced to three, by avoiding the necessity for the present second reheating of the ingot immediately on leaving the duplex hammer; and that the red heat of the ingot will never be lost from the time of casting till its completion as a finished tyre.

As an illustration of what can be accomplished with the present appliances, it may be named that in one instance the metal for making six steel tyres was run into the casting ladle from the large Bessemer converter at 6 5 a.m., the rolling of the first tyre was completed at 10 15 a.m., and the last tyre at 11 17 a.m.; making only 5 hours 12 mins. for the completion of the whole six tyres.

This mode of manufacture of tyres allows of all the material in the original ingot being used up in the finished tyre; a very trifling amount of metal alone is punched out in first forming the centre hole, and the material is afterwards simply displaced laterally and gradually worked outwards from the centre, as the hole is expanded from the beginning to the end of the process. The top of the conical ingot, instead of being cut off as a crop end of the full area of the ingot, as in the ordinary mode of manufacture from a parallel ingot, is reduced to only 6 inches diameter, which being in the centre of the ingot is at the part worked through by the punch, and remains at the inner side of the finished tyre, thus avoiding any risk of affecting the wearing face of the tyre. As another consequence of the very small area of the top of the ingot, the covering plate required in casting is so small and so thin that it is lost in the first reheating furnace by oxidation.

The saving of waste of material in this mode of manufacturing steel tyres has the important advantage not only of reducing the cost of manufacture, but also of allowing the total quantity of metal to be adjusted beforehand with great accuracy for the required size of tyre. Thus the 5 feet tyres, the size to which the dimensions of ingot previously given apply, are made from an ingot weighing 8 cwts., and the weight of the tyre finished from the rolls is a little more than 7¼ cwts.; so that the total loss by reheating in the process of manufacture is only 8 per cent. The required weight of ingot can therefore be calculated and provided for any given size of tyre; and the form of the ingot with the small area at top ensures a degree of uniformity not otherwise attained in the weight of the castings, as the whole extent of variation possible in the height of the ingot cannot cause any appreciable difference in the size of the finished tyre.

By this mode of manufacture of the tyres it will be seen that a very large amount of work is put into the ingot by the successive hammerings, before it enters the final rolling mill; and the effect of this in the writer's opinion is to cause a very considerable improvement in the quality of the tyres, rendering the metal mild and tough in a remarkable degree. The broken tyre that was

exhibited to the Members, when visiting Crewe yesterday, required nine blows from a weight of 21½ cwts. falling from a height of 22½ feet to break it.

Colonel KENNEDY was sure all the Members had been highly gratified by the excellent opportunity afforded them on the previous afternoon of witnessing the manufacture of the steel tyres at the Crewe Steel Works, and seeing the very admirable manner in which the whole of the operations were there carried out for the manufacture of locomotive work, together with the many important improvements that had been introduced. From the very valuable paper that had been read it would be seen with what complete success the Bessemer process had now been applied to the manufacture of tyres; and he should be glad to know some further particulars respecting the durability of the steel tyres in comparison with the best iron tyres, as he had always expected the material produced by the Bessemer process would give superior results to iron for such purposes.

Mr. J. L. ASHBURY remarked that it appeared from the paper that attention had hitherto been confined to locomotive tyres, as no reference was made to carriage tyres; and the applicability of the steel tyres for railway carriages and wagons must of course depend upon their relative cost as compared with the present carriage and wagon tyres of Yorkshire iron weighing about 3½ cwts. each and costing £22 per ton. At the present time there was no doubt whatever that a strong feeling prevailed among engineers in favour of steel tyres, more particularly for locomotive engines and tenders; but in the case of a large stock of as many as 15,000 or 20,000 railway carriages and wagons, there must of course be great

hesitation in adopting the Bessemer steel tyres if the cost were anything like as much as that of the cast steel tyres made of crucible steel, costing about £35 per ton. It was not any question of the quality of the steel tyres which retarded their adoption for railway carriages and wagons, but solely a matter of reduction of cost, as there appeared no reason to doubt that the steel tyres would have an advantage in durability over the present iron tyres. At the present time however, both in this and other countries, it was the exception and not the rule to have steel tyres; and a very considerable reduction in cost must take place before steel tyres could be generally introduced. There seemed some reason to anticipate such a reduction in the course of a few years' time, as far as could be inferred from the case of the Bessemer steel rails, the cost of which had originally been as much as £18 per ton, but was now reduced to only £12 per ton. The actual mileage of the steel tyres in comparison with iron tyres was another point upon which the general adoption of the steel tyres would depend, and this required to be very thoroughly ascertained. He suggested that the adoption of steel tyres for carriages and wagons would be very materially accelerated if it were possible to combine a steel face with a scrap-iron back in the tyres, whereby the cost would be greatly reduced below the present amount of £35 per ton for steel tyres, and would more nearly approximate to the cost of £22 per ton for best iron tyres.

Mr. RAMSBOTTOM replied that he had great reason to be satisfied with the results thus far obtained from the adoption of the Bessemer steel tyres for locomotive engines and tenders; he had become convinced previously that this material was the right one and completely safe for such purposes, having himself tested it in a variety of ways, both for axles, piston rods, and other purposes; and he had therefore felt no hesitation in recommending that the necessary plant should be put down for producing the Bessemer steel and manufacturing the tyres, having satisfied himself that a saving would be effected by the use of the steel tyres, and that it would be so far advantageous to manufacture them at the locomotive works at Crewe.

In the production of the metal in the converting vessel, he had followed Mr. Bessemer's instructions very closely; but in the subsequent treatment of the bloom he had departed from the beaten track by introducing the horizontal duplex hammer, together with the other special modes of roughing down the tyres into shape before rolling, which had been described in the paper and seen by the Members on the previous day, whereby the amount of labour expended upon the manufacture of the tyres was much reduced, while the work put into them was largely increased by the great amount of effective hammering that the bloom underwent. For the suggestion of the fireclay plug in the centre of the bottom of the casting mould he was indebted to his assistant, Mr. Webb; this was found very advantageous, and he thought the same plan might be adopted with advantage in other moulds, particularly where the melted metal had to fall from some height upon the bottom of the mould, so as to allow of that part of the bottom being readily renewed when it became worn. In reference to the hammering on the beck anvil, an improvement was now being made which he expected would supersede the beck hammer altogether, and reduce the time of that part of the process from about fifteen minutes as at present to probably not more than about two minutes; the whole operation being performed by a machine which he had designed for the purpose. The present method of hammering on the beck iron had first been brought under his notice by Mr. Allen of the Bessemer Works at Sheffield, to whom he was also indebted for the plan of giving the plain bevilled edge to the bloom, as shown in Fig. 18, Plate 67, for forming the flange of the tyre; and it was found in practice that this plain bevil was quite sufficient preparation for making the flange by the final rolling in the circular rolling mill, and was a most effectual means of obviating all necessity for forging a flange upon the bloom in the previous processes.

With regard to the durability of the Bessemer steel tyres, he was not yet in a position fully to compare them with the best Yorkshire tyres and Krupp's cast steel tyres from actual experience, as they had not yet been at work long enough for the purpose; but judging from the known durability of the material in other cases he had no

doubt that the new tyres would last for a very much longer mileage than the best Yorkshire tyres, and if not actually equal to Krupp's tyres would certainly approach them very nearly in durability. He had not used any tyres made with a scrap-iron back and steel wearing face, such as had been suggested, and had not yet applied the steel tyres to carriages and wagons, as the whole productive powers of the works had hitherto been fully occupied with the manufacture of locomotive tyres alone; but it was intended ultimately to carry out the same system for supplying the whole of the rolling stock with the steel tyres. For securing the tyre to the wheel a number of modes had been tried, and he had now five different methods in operation, which were being watched in order to determine the best plan; and his present opinion was that the ordinary attachment by means of rivets through the tread of the tyre would be found to outlast all the others.

The great object which he had had in view in adopting the Bessemer steel for tyres and carrying out the mode of manufacture described in the paper had been to obtain tyres of a mild quality of steel, which could be thoroughly relied upon for safety in running, as he considered it was of primary importance to look very closely to the question of safety for working in the manufacture of every portion of railway rolling stock. A practical proof of the safety of the Bessemer steel tyres was furnished by the tyre exhibited to the Members at Crewe on the previous afternoon, which had required the very severe treatment described in the paper in order to break it. Another of the tyres had been even more severely tested, and the value of the test would be readily understood by all in the habit of working steel. This tyre was a defective one, which had been made in one of the earlier experiments on the manufacture of the steel tyres, and it was very much cracked about the flange. It was first tested at a dull red heat upon the ordinary tyre-blocking press by hydraulic pressure; and this failing to produce any perceptible stretching, it was subsequently heated to a bright red heat and dropped tight upon a cast-iron block, and then suddenly quenched with cold water to make it shrink violently; but even by this treatment the tyre was not broken, though it was stretched about

$\frac{3}{4}$ inch in circumference. From these results he was confident that the Bessemer steel tyres of this mild quality were much better and safer than the best description of welded iron tyres; and quite as safe as weldless tyres of any description, whether iron or steel, irrespective of the mode of fastening the tyre on the wheel. The aim in adopting the Bessemer tyres had not been so much to obtain the highest scientific results, as the best commercial results, making safety in running the first consideration and keeping also in view the question of practical economy; and it was quite possible consequently that the material which was found so suitable for the tyres might not be so well adapted for other first-class engineering purposes as the best crucible cast steel.

Mr. F. J. BRAMWELL remarked that the test which had been mentioned, of heating one of the steel tyres and shrinking it on a cold solid block of cast iron, would be fully appreciated as a most satisfactory demonstration of the thorough safety under all circumstances of tyres made of that material in the manner described in the paper.

Mr. W. FAIRBAIRN enquired what had been the experience in the manufacture of the Bessemer steel tyres as to the uniformity in the quality of the material from which they were made. The difficulty attending the Bessemer process was not the actual production of the steel, but its production with sufficient uniformity of character, and it was very desirable to arrive at something closely approaching to practical uniformity. The practice was to add a given proportion of carbon to each charge of metal in the Bessemer converting vessel, in order to convert the metal into steel; but nevertheless the steel produced by this means did not always bear a uniform character. In the testing of iron boiler plates and ship plates he had found such a wide variation in the quality that some had double the strength of others; and as the strength of any structure was only equal to that of its weakest part, it was very desirable that uniformity should be arrived at in the manufacture of iron plates, and for the same reason this was equally important in the case of the steel tyres.

Mr. RAMSBOTTOM replied that the question as to the uniformity of quality of the Bessemer steel was a very important one, and he

thought it could now be fairly met by the results of experience. In dealing with iron there was a wide range of quality, and almost as great a range was found in steel. But comparing the Bessemer steel with crucible steel, the former was liable to a less extent of variation in quality than the latter, while the gradations of quality were as clearly discernible; and therefore at least as near an approach could be made to uniformity in the quality of the Bessemer steel as in crucible steel. He had indeed met with tyres made of crucible steel which had proved so hard that it had been almost impossible to turn them; but in his opinion this was much less likely to happen with the Bessemer steel. In the case of iron plates for boilers and other purposes, uniformity of strength might easily be ensured by rolling the plates rather larger than was required, and having a piece cut off each separate plate and tested; but for many purposes, such as girders, he thought plates of Bessemer steel would be safer and stronger than iron plates, on account of the soft and tough quality of the material. In connection with this point too little attention he thought was paid to the change of form occurring under strain, as a criterion of the practical value of any material, and to the amount of work that must be expended in producing this change of form before fracture could be effected. An illustration was afforded by the fact that a steel bar 12 inches long and requiring a tensile strain of 15 tons per square inch to break it might be elongated only $\frac{1}{4}$ inch before breaking, whilst an iron bar of the same length and requiring only half the tensile strain per square inch to break it might undergo three or four times as much elongation before breaking; and in like manner, to burst a bottle of lead by hydraulic power would require more work to be expended in pumping than to burst a glass bottle of the same dimensions; and the case was similar in regard to strains of compression. Thus a material which was the weaker in respect of its ultimate breaking strain might in one sense be the stronger; and hence the value of toughness in the material employed for such purposes as girders and boiler plates.

The PRESIDENT moved a vote of thanks, which was passed, to Mr. Ramsbottom for his paper, and for the excellent opportunity afforded to the Members on the previous afternoon of witnessing the whole process of the manufacture of the steel tyres at the Crewe works.

The following paper was then read:—

ON MACHINERY FOR THE PREPARING AND SPINNING OF COTTON.

By Mr. JOHN PLATT, of Oldham.

The object of the present paper is to trace the principal mechanical steps by which the application of machinery to Cotton Spinning has been developed, and which have led to the completion of the present elaborate machines, so remarkable for the perfection of the results produced by them. The modern machines are in fact formed of a combination of numerous highly ingenious contrivances, which have been successively designed to meet the special difficulties of dealing by machinery with so delicate and irregular a material as the raw cotton fibre.

The process of spinning involves three essential and distinct operations:—

First, *Drawing*,—in which the fibres of the raw material are drawn out longitudinally, so as to lay them all parallel with one another and overlapping at the ends; as is done by the fingers of the hand spinner for forming a continuous sliver out of the short fibres lying irregularly in the bundle that is tied upon the distaff.

Second, *Twisting*,—in which the sliver previously formed is twisted into a roving or thread, for giving it longitudinal tenacity by increasing the lateral friction between the fibres; as is done by the hand spinner by twirling the bobbin on which the portion of thread already twisted has been wound.

Third, *Winding*,—in which each portion of the thread, after it has been sufficiently twisted, is wound upon the bobbin.

In the application of machinery to the performance of these operations, the great difficulties experienced have arisen from the irregular character of the cotton fibre on the one hand, and on the other from the unyielding action of machinery, which has to take

the place of the delicate feeling of the fingers in hand spinning, whereby the spinner is enabled to accommodate the action continually to the variations in the material. It is a point of special mechanical interest however to note at how early a period in the application of machinery correct ideas were developed as to the principles of action in the important successive steps: so correct indeed that they have remained unaltered in principle to the present time, although many highly ingenious improvements in detail have subsequently been effected.

It appears that the credit of the first invention of the Spinning Machine is due to Lewis Paul in 1738, little more than a century ago, all spinning having been previously done by hand. In his first machine the raw cotton was passed through a succession of pairs of rollers, each pair running faster than the preceding, so as to draw out the sliver of cotton longitudinally to any degree of fineness required. The machine thus accomplished only the drawing process, leaving the sliver so formed to be twisted and wound afterwards by hand. The great feature of this invention was that the important principle of drawing by rollers running at different speeds was thus established at the outset, to supersede drawing by the fingers in hand spinning; and this mode of drawing has been adhered to ever since as the fundamental principle in the preparation of fibrous materials for spinning.

In 1748 Paul further invented a carding machine, for carding or combing the raw cotton in preparation for the drawing rollers. It consisted of a number of flat parallel cards fixed upon a table with spaces between them; and the teeth of the cards being all bent in the same direction, the cotton was carded by being drawn over them by hand by means of an upper flat carding board set with teeth bent in the opposite direction. In another arrangement this flat upper card was replaced by a horizontal carding cylinder, made to revolve by hand; and the lower carding table was made concave to fit the underside of the cylinder. When the cotton was sufficiently carded, it was taken off each card separately by hand by a needle-stick, and then connected into one entire roll or lap.

In 1758 Paul further improved his original machine by rendering it capable of performing the two other processes of twisting and winding requisite to complete the operation of spinning by machinery; and he constructed a spinning machine having a circular frame containing fifty spindles. The cotton was drawn by rollers, as in his previous machine, and the sliver was delivered from the rollers to a bobbin upon each spindle, by means of an arm or flier fixed upon the spindle; and the spindle being so contrived as to go faster than the bobbin, the sliver was thus twisted into thread by the flier, before being wound upon the bobbin.

Although the two mechanical principles which have formed the basis of all subsequent spinning machinery—namely the drawing rollers running at different speeds and the differential motion of the flier and bobbin—were thus originated by Paul, it does not appear that his machines were ever practically successful; and Arkwright's spinning machine in 1769, shown in Fig. 1, Plate 68, appears to have the merit of being the first that was brought into successful operation. This machine cannot be called more than an improvement in detail upon Paul's, as the principles of the two were the same; and it is difficult to imagine that Arkwright had not seen Paul's machine. The success of the later machine may be attributed to its superiority both in workmanship and in the material employed, the earlier machine having been composed almost entirely of wood.

The four pairs of drawing rollers A A, Fig. 1, were made of brass and steel, and geared together by pinions; the bottom rollers were covered with wood and fluted, and the top ones were covered with leather, and pressed down upon the bottom rollers by the weighted cords and pulleys B B. The sliver delivered by the rollers was then twisted into a yarn or roving by the flier C, and wound upon the bobbin D. The differential motion of the flier and bobbin, by which the two operations of twisting and winding were effected, was exactly the same that is still employed for the same purpose, only the motion was obtained by different means. If the flier and bobbin both revolved at the same rate and in the same direction, no winding would take place, and the effect would be confined to twisting the sliver into a roving. On the other hand if only the

flier revolved and the bobbin were stationary, all the motion would wind and also twist, but only a single twist would be put into the sliver for each coil wound on the bobbin. But if the bobbin rotates slower than the flier, the winding is effected at just so much slower rate than the twisting as the two speeds are made to approximate. This was accomplished in Arkwright's machine by the simple means of a friction break upon the bobbin D, the bobbin being loose upon the spindle and dragged round by the thread, whilst the flier C was fast upon the spindle and driven direct by the driving strap E below. The friction break to retard the bobbin was made by a worsted cord passed round a groove in the whirl F at the bottom of the bobbin, and tightened by hand to the required adjustment by a screw pin securing the end of the cord. The drag put upon the bobbin by this friction break also put a stretch upon the roving, and caused it to be wound tight on the bobbin in solid layers instead of in loose coils. In the arm of the flier C were fixed a number of hooks, under which the roving was passed; and the winding on the bobbin was done in successive steps, by stopping the bobbin and shifting the roving successively from one hook to the next on the flier, as no idea had yet been originated of giving the bobbin a vertical motion upon its spindle so as to guide the roving on regularly in winding.

In 1770 Hargreaves invented the Spinning Jenny, shown in Fig. 2, Plate 68, the principle of which is identical with that of the present spinning machinery. It thus presents a remarkable instance of a correct perception respecting the best mode of working having been attained at so early a stage in the application of machinery to a new purpose. The operation of spinning into threads the rovings produced by the machines already described, or by the modern improved machines similar in principle, comprises the two processes of twisting and elongating the roving to form it into a thread, and then winding the spun thread into the form of a "cop" upon the same spindle by which the spinning or twisting has been performed. These two processes still continue to be effected in essentially the same manner as in Hargreaves' spinning jenny.

The twisting of the thread is effected by causing the spindles G, Fig. 2, to revolve, as though for winding up the thread, but allowing the thread to slip off the free end of the spindle once in each revolution. For this purpose the thread is led off from the top end of the spindle at an angle so much greater than a right angle that its tendency to wind in a spiral brings it to the top extremity of the spindle in each revolution, causing it to slip off the end of the spindle at each successive revolution; and the top of the spindle is shaped conical to facilitate the slipping of the thread off the end. The result is that the thread is twisted one turn by each revolution of the spindle, without disturbing or interfering with the portion of spun thread already wound up into a cop on the lower part of the spindle. The crossbar J, carrying the guiding eyes through which the several threads pass, rests at each end on a carriage that runs along the side framing of the machine; and before the commencement of the spinning by the spindles G, the crossbar is first drawn backwards from the spindles by hand through about one third the length of the machine, drawing off a continuous supply of roving from the bobbins K below, which are free to turn on their bearings. The clasp H is then pressed down tight upon the crossbar J, holding the rovings fast, and the spindles G are set in motion, twisting the lengths of thread between the spindles and the crossbar; and during the twisting the crossbar is gradually drawn backwards by hand to the end of the machine, thus producing the required elongation of the threads by tension during the spinning, as is done in the case of hand spinning by the weight of the bobbin or spindle hanging from the twisting thread. The spindles G receive their motion from the drum M driven by the driving pulley L, which is turned with the right hand by the handle N, while the left hand draws back the crossbar J by means of the handle upon the clasp H.

When the crossbar J has been drawn back to the extreme end of the machine and the spinning of the threads has been completed, they are then wound up on the spindles by depressing them all simultaneously to the lower portion of the spindles by means of the "faller wire" O, which is brought down upon the threads by the rotation of the discs P P in the direction of the arrow. The rotation

of the discs is effected by tightening the cord R which runs along the side of the machine, and they are turned back again by a counterbalance weight for raising the faller wire when the cord is released; the cord passes round three horizontal pulleys on the top of the carriage S, and is tightened for depressing the faller wire by a transverse sliding movement being given to the middle pulley by means of a hand lever, which is worked by the left hand whilst holding the clasp on the crossbar J. The threads being depressed by the faller wire, the further rotation of the spindles now causes the threads to be wound up in cops upon the spindles, the sliding crossbar J being pushed forwards gradually by hand as the winding proceeds, until it again reaches the spindles, when it is ready for beginning the spinning of a fresh length of rovings. During the winding of the threads already spun between the spindles and the crossbar J, this length of the threads is secured and separated from the untwisted rovings beyond the crossbar by the pressure of the clasp H, which is kept pressed down tight upon the threads.

On the completion of the spinning however of each length of the threads, and before the change can take place from spinning to winding, it is necessary first to unwind the short spiral of thread extending up from the top of the cop previously wound to the top extremity of the spindle. This spiral is unavoidably formed at the commencement of the twisting, before the thread can reach the point where it ceases to wind and begins slipping off the end of the spindle at each revolution; but if this portion of thread were not entirely removed before the faller wire O is lowered at each time of changing from twisting to winding, an irregular and loose accumulation of thread would take place upon the upper end of the spindle, spoiling the form of the cop and interfering with the proper slipping off action in twisting. The motion of the spindles has therefore to be stopped and reversed for a few turns when the twisting is finished, to unwind these few spiral coils; and this was done in the spinning jenny by the spinner stopping the driving wheel L, and then giving it a partial turn backwards by hand, for "backing off" the thread, before driving forwards again for winding the thread on the spindles.

This backing-off motion and the faller wire are identical with those now in use in the modern spinning machines, the only difference being that they are now made self-acting. In winding the cop each successive layer of thread is so regulated that a conical form is given to each end of the finished cop, in order to prevent the thread from getting loosened upon it at the ends in subsequent handling; while at the same time the crossing of the thread in the alternate spiral layers gives firmness to the cop, and still allows the thread to be afterwards drawn off it, when required for use, either by slipping off the end as in a shuttle, or by unwinding the cop on a spindle. In the spinning jenny this shape of cop was obtained by regulating the winding of the thread by means of the cord R acting upon the discs P P, raising and lowering the faller wire O during the winding so as to guide the thread upon the spindle as required for producing the desired shape of cop. The same shape of cop and mode of guiding the thread on are still adhered to in the present spinning machines; but the whole of the movements are now effected entirely by self-acting machinery.

Further improvements in the preparatory processes of carding and roving were introduced by Arkwright in 1775, which may be said to include the principal features contained in the carding and roving machines now used. The cotton delivered from the preliminary machine was formed into a roll or lap, for supplying a continuous fleece of cotton to the carding cylinders, the carding operation being repeated until the irregular mass of fibres in the raw material had been combed straight and laid parallel in the fleece of cotton with a sufficient degree of uniformity to allow of proceeding to the subsequent operations. Comb-plates worked backwards and forwards by cranks were also added for combing off the cotton in a continuous fleece from the "doffer" or taking-off cylinder of each of the carding machines. The sliver delivered from the last carding process was passed between a pair of rollers for the purpose of consolidating it by the pressure of the rollers after the loosening action of the doffing comb-plate; and it was then coiled down into a can.

The doubling and drawing process employed at this stage of the manufacture was also introduced by Arkwright at the same time, the object being to intermingle the fibres more completely in the sliver and thereby render it more uniform in quality, ready for twisting into a roving. For this purpose two or generally more of the slivers from the carding engine are passed side by side through a series of pairs of drawing rollers, each pair in succession being made to run faster than the preceding; and the last pair of rollers runs as many times faster than the first pair as there are slivers doubled together, so that the single combined sliver delivered from the rollers is drawn down to the same size or weight per foot as one of the original slivers. The doubling and drawing operation is usually repeated three times, and the ultimate sliver so prepared is then ready for the roving frame, in which it is again drawn and twisted and wound upon a bobbin.

In the roving frame Arkwright now effected an important advance upon his previous machine, shown in Fig. 1, by introducing the new principle which has since been adhered to, of driving the bobbin and the spindle independently by separate motions, instead of letting the bobbin be simply dragged round by the thread as previously described. At the same time he also introduced the conical regulating drum, for reducing the speed of the bobbin in proportion as its diameter was increased by the thickness of the coils of roving wound upon it, so as to avoid increasing the tension upon the roving as would be the case if the speed of the bobbin were uniform, since the spindle and flier are driven always at a constant speed. This mode of regulating the speed of the bobbin by a conical drum is the same that is still employed in the modern machinery, with modifications only in the mode of application. There appears reason also to believe that the rising and falling motion of the bobbin upon the spindle, for winding the roving on the bobbin in regular coils by a continuous vertical movement of the bobbin, was also introduced by Arkwright at the same time, although no description is given by him of the manner in which this was accomplished; but in the drawing illustrating the series of improvements introduced by him at that period, the flier upon the spindle is shown with a single

eye for delivering the roving upon the bobbin, instead of the succession of hooks fixed on the arm of the flier in the previous machine, Fig. 1, for winding the roving on in a succession of steps; and a sufficient space is also left in the drawing for allowing the required amount of vertical movement of the bobbin. The invention of this principle of lifting and lowering the bobbin upon the spindle during the winding, which is employed in all the present machines, has not been traced by the writer to any earlier date than these final improvements introduced by Arkwright in 1775.

By thus making special machines for each process in the preparation of the material for spinning, Arkwright effected a most important division of labour; and the factory system, already introduced in the silk manufacture, became rapidly extended in consequence.

In the preparation of cotton the improvements introduced from time to time in each particular section of the machinery employed have been so numerous and so varied that only a slight reference can be made to them in this paper under their respective heads, in the hope that they may be made the subjects of special papers by some of the Members at future meetings.

Opening.—The first process in the preparation of the raw cotton was known as "willowing," and took its name from the willow switches formerly used for beating or opening the tufts of cotton by hand. A number of small parallel cords were stretched tight and close together on a horizontal frame, so as to form a sort of table, upon which the cotton to be opened was laid; and the cotton being then beaten with switches made of willow rods kept smooth for the purpose, the fibres of the cotton remained on the cords, whilst the sand and seeds fell through between. Some of the best descriptions of sea-island cotton are still batted in this way, for the finest counts of yarn. Several attempts were made to work the willow beaters by machinery, but they have all been superseded by opening and scutching machines on the modern principle, having revolving cylinders to act as beaters. The most primitive of these is known

as the Oldham Willow, and has a revolving cylinder about 36 inches diameter, set with spikes placed in parallel rows, and revolving against a grid of bars set with similar spikes: the cotton is fed upon the grid and beaten for a longer or shorter time according to its condition, and an exhausting fan is employed for taking away the sand and bits of dried leaves beaten out. This machine is now used only for separating hard lumps of cotton in bales packed too tightly, and for cleaning cotton waste and the refuse cast out by other cleaning machines.

Fig. 3, Plate 69, shows a section of the Cotton Opener in use at the present time for the purpose of opening out the fibres of the cotton after it has been pressed in the bales, and for extracting the sand, dried leaves, and other impurities imported with it, the object being to do this without entangling or injuring the fibre. The crude cotton from the bales is spread by hand upon the endless travelling lattice A, which conveys it underneath the iron guide-roller B with longitudinal ribs on its surface to the pair of fluted feed-rollers C. These are pressed together by the weighted lever D, and deliver the cotton to the picker cylinder E set with twelve rows of teeth, which are spaced so that the teeth follow one another spirally round the cylinder, as shown in the plan, Fig. 4. The tufts of cotton being gripped tight between the rollers C are caught by the tips of the teeth on the cylinder revolving in the direction of the arrow, and are thus torn open and dashed by the teeth against the circular grid F, formed of angular bars set with spaces between them, which allow the dirt disengaged by the beating action to fall through. A perforated plate G forms the remainder of the casing of the cylinder on the underside, allowing the dust to drop through while the cotton passes over it. The picker cylinder delivers the cotton against the teeth of the beater H, which has four rows of teeth, similar to those on the picker E. Here the cotton is further beaten and passed over a circular grid and perforated plate; and the beater cylinders being covered in at the top by a sheet-iron casing, the current of air produced by their revolution wafts the light fleece of cotton forwards over the straight grid J. It is whilst the cotton is thus floating in the air that the heavier impurities,

loosened by the beaters, drop out and fall through the grid J into the dust box. The cotton then passes between the two wire-gauze cylinders K, which serve as fine sieves, the interior of the cylinders being exhausted by the fan L; by this means the more minute particles of dust remaining in the cotton are sifted out, and discharged by the fan through the aperture M, thereby keeping the rooms where the machines are at work perfectly free from dust. There is thus a continual deposit of impurities taking place throughout the whole passage of the cotton through the machine, from the feed rollers C to the wire cylinders K. In the drawing only two beater cylinders E and H are shown; but the machines are more generally made with four cylinders, for cleansing the cotton more effectually, the two additional beaters being provided with four rows of teeth, the same as the second cylinder H. From the wire cylinders the loose cotton is collected again and consolidated into a fleece by the fluted stripping rollers I, running close to the cylinders K but not touching; and these deliver it to the travelling lattice N, which discharges it ready to be taken to the next process of scutching, a lap machine being sometimes attached so as to form the fleece into a lap or roll for supplying the scutcher. The beater cylinders E and H run at about 1000 revolutions per minute; the feeding lattice A travels at 6 feet per minute, which is also the surface speed of the feed rollers C; and the surface speed of the wire cylinders K, the stripping rollers I, and the delivery lattice N is 60 feet per minute.

Scutching.—The Scutching Machine now in use for further beating and cleansing the cotton delivered from the opener is shown in Fig. 5, Plate 70, having also combined with it the Lap Machine for forming the fleece of cotton delivered from the scutcher into a roll or lap. The cotton from the opener is supplied to the scutcher upon the travelling feeding lattice A, and in order to produce a uniform fleece for the further processes it is necessary at this stage to regulate the quantity fed into the scutcher, which is effected in two ways. In feeding by hand the tedious method of weighing the cotton supplied has to be resorted to, so as to distribute a uniform weight of cotton

over each foot of length of the feeding lattice, which together with the feed rollers C is driven at a uniform speed. But in the improved mode of feeding by laps B, supplied from a lap machine in connection with the opener, the top feed roller is allowed to rise and fall according to the variations in the thickness of cotton fed in, and the amount of its vertical movement multiplied by means of levers is employed to regulate by a self-acting arrangement the speed at which the feeding lattice and rollers are driven. By this means an almost uniform supply of cotton is fed to the beater H, which is composed of three plain bars, as shown in the plan, Fig. 6, and is driven at about 1250 revolutions per minute. The cotton is beaten as before against the circular grid F and perforated plate G, and the current of air from the beater wafts it forwards over the straight grid J to the wire cylinders K exhausted by the fan L, the action being exactly the same as in the opening machine. The rollers I which strip the dust cylinders deliver the fleece to a set of four callender rollers O placed over one another, so that the cotton in passing through them receives three compressions, which consolidate it into a kind of felt; the surfaces of the callender rollers are kept clean by rubbers of iron covered with flannel, which are pressed in contact with them.

The Lap Machine, for coiling the fleece into a roll or lap, has two fluted driving rollers P P running in the same direction, as shown by the arrows; and the lap resting in the channel between them is driven by contact, and wound upon the iron rod R guided in a vertical groove at each end. For tightening and closing the coils of the lap, the rod R was weighted in the former machines by a heavy weight suspended from the ends of the rod, and it was then necessary to lift the whole of this weight at each time of changing the lap; but this is now effected by the friction break S pressing against a friction wheel on the shaft T, on which are pinions gearing into the vertical racks U, and these racks carry rollers at the top, bearing down upon the ends of the rod R in the lap. By this means, as each successive coil is wound upon the lap, the break S slips and allows the lap to rise; and when the lap is completed the break is released by a treadle, and the racks are

lifted clear by the handwheel on the shaft T, so as to allow the finished lap to be removed. The driving pinion V, from which the callender rollers O receive their motion, is held up in gear by the lever W supported by a catch; and when the lap is finished this catch is released by a tappet upon the pinion X, which is driven from the bottom callender roller, the speed of the pinion being so reduced that one revolution of it corresponds to the size of lap required to be made. The catch being released allows the driving pinion V to fall out of gear, whereby the callender rollers O are stopped; and the lap rollers P continuing to revolve break off the fleece, ready for removing the finished lap from the machine. By changing the pinion X carrying the tappet, the size of lap made by the machine can be varied as desired.

The scutcher shown in Fig. 5 is a single machine, and it is usual to pass the cotton first through a double scutcher of similar construction, but having a second set of feed rollers with beater and wire cylinders, running at a higher speed; the second pair of wire cylinders and stripping rollers are driven three times as fast as the first pair, so that they deliver a fleece of one third the thickness first supplied to the machine. Three of the laps from this double scutcher are then fed into the single scutcher shown in the drawing, as at B B B, Fig. 5, being spread upon the surface of the feeding lattice A in three layers on the top of one another, so as to present to the feed rollers a uniform fleece equal in thickness to that fed into the first scutcher. By thus doubling the laps the fibres are more thoroughly mixed, and the fleece is thereby made more uniform in thickness.

Scutching machines having a revolving beater, composed of two plain bars describing a circle of about 14 inches diameter, were introduced about 1810; and these machines contained also a travelling feed lattice, two pairs of feed rollers, and a second travelling lattice for conveying the beaten cotton underneath a perforated revolving cylinder, the interior of which was exhausted by a fan. The cotton passing through this machine was delivered in a loose fleece, and a few years later a lap machine was added for coiling the fleece into a lap. Other improvements have gradually

been introduced up to the present time, as regards both design and workmanship: the cylinders and beaters have been put in perfect balance, so as to revolve steadily at the high speed required, and the forms of teeth on the cylinders have been arranged for greater strength and greater facility of construction; stronger and simpler gearing has been employed, improvements have been made in the form and construction of the bearings of the beaters and other quick revolving shafts, so as to ensure more efficient lubrication, and air-tight dust boxes have been added with moveable doors for facility of cleaning; and the self-acting arrangements have been introduced for stopping the machine when a given length of fleece has been delivered, and for regulating the rate of feed according to the thickness of the cotton supplied, so as to dispense with the previous plan of weighing the cotton in feeding. Thus by successive improvements through a long series of years the difficulties which originally presented themselves in the successful adaptation of machinery to cotton cleaning have been overcome; the cotton can now be perfectly cleaned without injury to the fibres, and the laps are produced uniform in length, breadth, and thickness of fleece, and so thoroughly felted that they uncoil at the carding engine in the next process without any derangement of the felted fleece.

Carding.—In the carding process the felted fleece delivered by the lap machine of the scutcher, with its fibres crossed in all directions, is combed out a great number of times so as to straighten the fibres; and the light impurities still adhering to it are taken out, such as short fibres and bits of the moss-like covering of the seeds, which if allowed to remain in the sliver produced by this operation would give a roughness to the yarn. For making coarse yarns one carding process only is employed; but for finer yarns the fleece is first passed through a "breaker" carding engine, which performs the first rough carding, and the slivers delivered by this are then "doubled" by laying together a large number of slivers, side by side and overlapping one another, into a new fleece, so as to obtain sufficient thickness and breadth of material to allow of a

further carding; and the lap formed of this new fleece is then fed into a second or "finisher" carding engine. As many as 96 slivers from the breaker card, each drawn out of a separate can, are laid together by the doubling machine into a single fleece for the supply of the finisher, in order that the mixing of the cotton may be more thoroughly effected, and more perfect uniformity ensured in the sliver delivered by the finisher. For the finest qualities of yarn the finisher card is itself used as a breaker, and the sliver delivered by it is afterwards combed by a combing machine.

The Roller and Clearer Carding Machine employed at the present time as a breaker card for performing the first carding of the fleece is shown in section in Fig. 7, Plate 71; and consists of a main carding cylinder A, round which are arranged a series of pairs of carding rollers or "workers" B B and clearing rollers or "strippers" C C. The surfaces of all these are covered with cards, and they are made to revolve so close together as to allow the tips of the card teeth just to clear one another. The cards are a kind of wire brush with inclined teeth, as shown full size in Fig. 9, and are made of staples D of fine steel or iron wire, each about 3-8ths inch long and 3-16ths inch wide, with a side bend in the middle of their length. These are fixed close together into a strip of webbing about $1\frac{1}{2}$ inch wide, which is wound tight round the cylindrical rollers in a continuous spiral, keeping the staples pressed home in the cloth by the surface of the cylinder, so that they have an elastic firmness which keeps their points up to the work.

The working width of the machine is about 40 inches on the card teeth, corresponding with the breadth of the fleece in the lap E by which the carding engine is fed. The unlapping of the fleece is performed by the rollers F on which the lap rests, and the fleece is then drawn forwards under the feed roller G, and delivered to the taker-in roller H revolving in the direction of the arrow. At this point the carding or combing action commences, the fleece being held by the feed roller G travelling at the slow speed of only about $\frac{3}{4}$ foot of surface per minute, while the taker-in H runs much faster, at about 800 feet per minute surface speed; and the carding teeth on the taker-in being bent forwards in the direction

of motion, the points of the teeth strike down into the fleece held by the feed roller, and comb out the fibres, while the impurities separated fall to the ground. The fibrous tufts of cotton are carried round on the underside of the taker-in to the main carding cylinder A, which revolves in the same surface direction with a speed of about 1600 feet per minute. The teeth of the carding cylinder being bent forwards in the direction of motion sweep off the cotton from the taker-in teeth inclined in the same direction but running at only half the speed, and carry it forwards to the dirt roller J, the teeth of which face those of the carding cylinder, and travel with a very slow motion of only about 16 feet per minute. The dirt roller thus assists in combing out the fibres, and holds in the interstices of its wires any impurities that it receives from the cotton, which are carried forwards and stripped from it by a vibrating comb, so that they accumulate in a roll on the upper surface of the dirt roller, to be taken away by hand at intervals.

The carding cylinder then carries the cotton forwards to the several pairs of workers and strippers, one of which is shown to a larger scale in Fig. 8; and at each pair in succession the fibres undergo a further combing out and straightening. The motion of the teeth of all these pairs of rollers is in the same direction as that of the adjacent teeth on the main carding cylinder, as shown by the arrows in Fig. 8, but at a much slower speed; and the teeth of the strippers C are inclined forwards in the direction of motion, while those of the workers B are set the opposite way so as to present the points of the teeth facing those on the carding cylinder A. The cotton on the carding cylinder is therefore carried past the stripper C without being caught by its teeth, and is caught upon the teeth of the worker B running at only about 20 feet per minute, so that a combing action for straightening the fibres and dividing the tufts of cotton is obtained by the excess of speed in the carding cylinder running at the high velocity of 1600 feet per minute. All fibres failing to pass the worker B are carried round upon its teeth to the stripper C, which runs at a surface speed of about 400 feet per minute, being thus intermediate in speed between the slow worker B and the quick carding cylinder A;

the teeth of the stripper therefore sweep off the cotton from the worker, and are themselves stripped in the same way by the carding cylinder running at the higher speed. After passing the six pairs of workers and strippers, the fleece of straightened fibres is taken off in a continuous sheet from the carding cylinder A by the doffer K, the teeth of which face those of the cylinder and move in the same direction but at a much slower speed of only about 65 feet per minute; the fleece thus receives a further straightening and stretching in quitting the carding cylinder, and is carried round on the underside of the doffer to the vibrating comb I, which describes a short arc of $1\frac{1}{4}$ inch vertical motion and is driven by balanced cranks at about 800 double vibrations per minute. This comb strips the fleece from the face of the doffer in its down stroke and clears itself in rising; and the thin fleece, of the full width of the machine, 40 inches, is then gathered in by lateral guides to a width of 6 inches, and finally into a smooth bell-mouthed round funnel L, having a hole only $\frac{1}{2}$ inch diameter, through which the contracted ribbon or sliver is drawn by the two pairs of drawing rollers M, the second pair running one half faster than the first, whence it passes to the coiler N and can O.

The coiler consists of a revolving plate N having an eccentric aperture, through which the sliver is passed from the pair of rollers P above the plate, so that it is delivered into the can in circular coils. The can O however is also made to revolve with a slow motion in the opposite direction to the coiler, and the centre line of the coiler N is eccentric to the axis of the can, whereby the sliver delivered from the coiler describes a succession of hypocycloid curves in the can, the circles of sliver being laid into the can so that the outsides of the coils touch the inside of the can. The sliver thus forms coils continually crossing one another, so that the can is filled up solid throughout, and when taken to the doubling frame the coils of sliver come out again without adhering to one another.

The Flat Carding Machine employed at the present time as a finisher card for performing the second carding operation is shown

in Fig. 10, Plate 72; and consists of a main carding cylinder A, as in the breaker card, but the pairs of workers and strippers employed in the first carding are here replaced by a series of flat cards D D, connected together by links so as to form an endless travelling lattice. The lap E, formed of a number of slivers from the breaker card laid together into a fleece by the doubling machine, is supplied to the carding cylinder A by the feed roller G and taker-in H, in the same way as in the breaker card; and the carding cylinder A is driven at the same speed of about 1600 feet of surface per minute. A single worker B, called the fancy roller, with a stripper C, is placed immediately beyond the taker-in H, running in the same direction as the adjacent surface of the carding cylinder A; but in this case the teeth of the fancy roller B are bent forwards in the direction of motion, and it therefore requires to be driven at a higher velocity than the carding cylinder, and has accordingly a surface speed of 2000 feet per minute. It thus seizes the cotton from off the teeth of the main carding cylinder A, and throws it against the teeth of the stripper C facing those of the fancy roller; and the fibres having thus been subjected to a preliminary carding are again swept off the teeth of the stripper, moving at only 400 feet per minute, by the higher speed of the main carding cylinder A.

The cotton is then carried forwards by the carding cylinder to the series of flat cards D D, Fig. 12, Plate 73, which are made of cast-iron bars faced with card teeth, as shown to a larger scale in Figs. 14 and 15; these extend the entire width of the machine, and rest at each end upon a circular guide on the top of the side frames of the machine, which is concentric with the main carding cylinder A, so that the teeth of the flats are kept in close proximity to the teeth of the carding cylinder during the whole of their forward traverse. The teeth of the flats D are set to face those of the carding cylinder A, and travel forwards in the same direction as the surface of the cylinder, but at a very slow rate of only 1 inch per minute; and the cotton thus undergoes a very thorough carding and straightening in passing the twenty-one cards that are always in contact with the top of the carding cylinder. The flats are arranged to work at a slight inclination to the surface of the carding cylinder, so that the

delivering side of each flat is closer to the cylinder, and a wider space is left at the entering side between the flat and the cylinder for the cotton to enter, as shown half full size in Fig. 15. The angle thus formed is called the bevil of the flat, and the correct adjustment of this inclination is a point of great importance and delicacy; the bevil is obtained by cutting a bevil groove Q in each end of the flat at the part where it is to rest upon the circular guide on each side of the machine, as shown enlarged in Figs. 14 and 15, where the dotted circle X X represents the edge of the guide on which the flat travels, and the dotted circle Y Y indicates the surface of the main carding cylinder A.

The endless lattice of flats D D is carried over the three shafts P P P, and on quitting the carding cylinder A each flat in turn is stripped of any fibres or impurities adhering to it by the vibrating comb R, which describes an arc of 1 inch and is driven at the rate of 40 double strokes per minute by the cam S, Fig. 13. The flats are further cleaned by the brush T, shown in plan in Fig. 11, running at a surface speed of 50 feet per minute; and they are then passed over a guide U, which holds them up against an emery wheel V running at the high speed of 550 feet per minute and traversing across the machine along the length of the flats, whereby the faces of all the cards are successively ground to a true surface whilst at work, and the points of the wires sharpened. The same mode of grinding is also employed for keeping true the surfaces of the carding cylinder and doffer. The fleece of straightened fibres is taken off in a continuous sheet from the carding cylinder by the doffer K and vibrating comb I, and is contracted into a sliver and coiled down into the can O in the same manner as previously described.

In Arkwright's improved form of the early carding engine the upper portion of the carding cylinder was covered over by a series of bars of wood called "top flats," the underside of which was covered with card teeth facing the teeth of the cylinder. These flats were stationary, held in their places by pins fixed in the framing, and were adjusted to the required bevil by two set-screws at each end; and they were lifted off and stripped of their refuse by hand cards at

intervals. The stripping by hand labour however was an unhealthy and disagreeable process; and as bad work and spoiled cotton were the consequence whenever it was not done regularly and thoroughly, many arrangements have been introduced from time to time for stripping the flats mechanically. In this direction Messrs. Buchanan of Catrine and Mr. Bodmer of Manchester led the way, although the machinery employed by them was never generally adopted. Within the last few years however a much simpler mechanism for this work has been introduced by Mr. Wellman, an American, the application of which has received a great stimulus from the difficulty of obtaining men to perform the stripping by hand; and it is now extensively used. Metal flats were introduced by Mr. Smith of Deanston, and these were linked together in the form of an endless lattice, which was made to travel slowly forwards over the carding cylinder; and each flat was adjusted to the proper bevil by two screws at each end, which travelled over two circular guides concentric with the carding cylinder. Another short flat guide at the back of the flats brought them into contact with a stripping brush, which was cleaned by a comb, and the comb teeth were scraped clear by a tin knife. These flats were used in several of the Scotch mills, but few of them were introduced into Lancashire. The flat carding machine was further improved by Mr. Evan Leigh, by cutting the bevil on the ends of the flats, as shown at Q Q, Fig. 14, and making the circular guides over which they travel adjustable for wear; at the same time a second face was formed on the back of the flats, to work over the guides U, Fig. 12, which hold them up in the right position for being ground by the emery wheel V; and the vibrating comb R was also added for stripping the flats before they are finally cleaned by the brush T, instead of the brush alone being used for the purpose.

The finisher carding machine until recently was constructed without the taker-in roller H, Fig. 10, the main cylinder taking the fleece direct from the feeding roller G. This caused the fibres to clog the cards, and any impurities passing the feed roller damaged the teeth of the main cylinder, which was of serious importance on the large extent of surface of the cylinder. By using the taker-in however these evils are prevented, the fibres being delivered to the

carding cylinder in a more divided state, and more equally distributed over its surface. Carding machines are also sometimes made which are a combination of the breaker and finisher card, having rollers and clearers on the side of the cylinder next the feeder, and flats on the side next the doffer.

The practical difficulty originally experienced with the carding engine consisted in getting the cards to work sufficiently near to one another without occasionally coming in contact, which destroyed the carding points. The surfaces on which the cards were fixed were generally constructed of wood, and therefore varied with every change of the atmosphere from the shrinking or swelling of the wood, so that the faces of the cards had to be made true each time by grinding down the points of the wires at the full parts. Moreover the cylinders and rollers were not carefully constructed so as to run with a steady motion; and the fixings for carrying the different journals were not capable of a fine adjustment, nor were they steady after being set. These defects are now overcome by using iron instead of wood, and by the aid of machinery and tools adapted for making all the parts accurately; fine adjustments are provided, and the adjustable portions are made as firm when set as if fixed. These improvements cause less grinding and stripping to be required, as the finer and truer the points of the wires can be maintained, the clearer the cards continue in working; and thus the carding engines have now been brought into their present successful and extensive operation.

Drawing.—The slivers from the finisher card are next taken to the Drawing Frame, shown in section in Fig. 16, Plate 74; which contains generally four pairs of drawing rollers A, each pair running faster than the preceding, and the front pair running at six times the surface speed of the back pair. Six slivers B in separate cans from the carding engine are fed up together to the back pair of drawing rollers, being combined together by passing between two guide pins C; and after being laid together and drawn out to six times the original length, the single sliver so produced is passed through a funnel to the pair of callender rollers D, by which it is delivered to the coiler E, and

coiled down into the can F in the same manner as in the carding machines. This combined sliver having been doubled six times and drawn six times is the same weight per foot as each of the original slivers fed up to the back pair of rollers; and the object sought in the doubling and drawing process is to equalise the distribution of the cotton fibres and produce slivers of more uniform strength and texture by the combination. The process is repeated three times in this machine, and the extent of combination or intermixture obtained in the ultimate slivers is therefore represented by the cube of six or 216 times, in comparison with each of the original slivers first supplied to the machine.

In order to ensure the drawing rollers being always supplied with the full number of six slivers, each of the slivers fed up to the rollers is passed over a guide G, turning on a centre pin and nearly balanced, so as to turn with a slight pressure; and during the working of the machine this guide is depressed by the weight of the sliver into the position shown by the full lines. But in the event of the sliver breaking or running out, the tail of the guide being overweighted drops into the position shown by the dotted lines, and catches the vibrating finger J, which is worked by an eccentric on the shaft H running at 70 revolutions per minute. This shaft is driven at the end by a small crown ratchet-clutch, held in gear by a spiral spring behind and driving by the inclined faces; so that, whenever the shaft H is stopped by the tail of a guide G catching one of the vibrating fingers J and the ratchet is consequently held stationary, the clutch is thrown out of the ratchet by the inclination of the teeth, and the end motion thus produced releases a catch which holds the strap fork of the machine; the fork is then reversed by a spring always acting upon it to throw off the strap from the fast to the loose pulley, thus stopping the machine. After the sliver run out has been renewed or the broken sliver joined up by the attendant, the machine is set in motion again by moving the starting rod I which extends the whole length of the drawing frame.

The improvements made in the drawing frame since its introduction by Arkwright include, amongst other details, the

construction of the roller supports so as to be easily set and adjusted to the different distances required to suit the different lengths of cotton fibre worked; the addition of the self-acting stop motion, for stopping the machine when any one of the slivers breaks or runs out; a simpler mode of suspending the weights from the top rollers; and the use of an endless travelling cloth over the surfaces of the top rollers, as shown in Fig. 16, for cleaning off the waste or "fly" from the rollers. The top rollers are also made with dead spindles and loose bosses, the bosses being driven by independent motions. In drawing frames used to prepare slivers for the finer counts of yarn, an additional stop apparatus is provided for stopping the machine whenever a breakage of the sliver occurs between the front pair of drawing rollers and the callender rollers D, Fig. 16, or when the can F is full or a given length of sliver has been delivered; this stop action is worked from the same shaft H as that employed for breakages of the supply slivers.

Slubbing, Intermediate, and Roving.—The slivers delivered from the drawing frame are conveyed to the Slubbing Frame, into which they are fed either single or double, passing over a guide, like that in the drawing frame, to a set of three pairs of drawing rollers; the last pair runs at five times the speed of the first, so that the sliver is again increased in length five times in passing through the rollers. From the drawing rollers the sliver, now called "slubbing," passes to a revolving flier carried upon a vertical spindle, by which it is twisted and then wound upon a bobbin revolving loose upon the same spindle. The flier runs at a constant speed, while the bobbin is driven by means of a differential motion at a speed varying according to its increasing diameter as the slubbing is wound on; and the lifting movement, for raising and lowering the bobbin upon the spindle so as to wind on the slubbing in regular coils, is also worked by the same differential motion. The speed of the flier is 500 revolutions per minute, and the slubbing is delivered from the drawing rollers at the rate of 50 feet per minute, so that the number of twists put into it in this machine is $\frac{5}{6}$ twist per inch of length.

The bobbins from the slubbing frame are next supplied in pairs to the Intermediate Frame, in which the slubbings are doubled by passing two of them together through a set of three pairs of drawing rollers, and then twisting them into one by means of a flier, and winding on a bobbin in the same manner as in the slubbing machine. In this process, "intermediate" between the slubbing and roving, the amount of drawing produced by the rollers is 5 times; and $1\frac{1}{4}$ twists are put into the doubled slubbing by the flier per inch of length delivered from the rollers.

In the Roving Frame, shown in Fig. 17, Plate 75, the contents of two bobbins A A from the intermediate frame are again doubled, drawn, and twisted as before; and the cotton, now called "roving," is wound upon bobbins ready for being finally spun into thread. The extent of drawing in the three pairs of drawing rollers B is 6 times, and the front pair runs at a surface speed of 29 feet per minute; the flier C is driven at 900 revolutions per minute, and thus puts $2\frac{1}{2}$ twists per inch into the roving. The bobbins A A supplying the cotton for the rovings are fitted upon wood spindles called "skewers," pointed at the lower end where they rest upon their bearings, which are shallow cups made of glazed earthenware; these are found very durable, lasting for twenty years before requiring renewal, but when brass or cast-iron bearings were previously tried they were found to be worn through in as many months, whilst the skewers made of lance wood were but little worn. The spindles D carrying the fliers are driven by skew-bevil wheels on the shafts E at the bottom of the machine. The bobbins F are loose upon the spindles, and are driven by skew-bevil wheels on the shafts G, carried in the bobbin-lifter H, which supports the bobbins and gives them the vertical movement on the spindles D for winding the roving in uniform coils from top to bottom of the bobbins.

As the winding is effected by the difference of speed between the bobbin and flier, both of which revolve in the same direction, the speed of the bobbin may either exceed that of the flier, or the converse; and both plans are in use in the present machines. When the bobbin runs in advance of the flier, the speed of revolution of the bobbin has to be gradually diminished as its diameter increases

by each successive layer of roving wound on; otherwise the delicate roving would be irregularly stretched or broken by the relatively increasing surface speed of the bobbin, as the speed of the drawing rollers B and the flier C is required to be constant in order that an equal amount of twist may be put into the roving throughout its entire length. On the other hand when the bobbin follows the flier, its speed of revolution has to be gradually increased as its diameter increases by winding. In either case the vertical reciprocating movement of the bobbin-lifter H has to be gradually retarded, to allow a longer time for winding each successive layer of roving upon the increasing circumference of the bobbin; and the length of the vertical motion is also diminished at each reciprocation, so as to give the required conical form to the ends of the bobbin, which is effected by means of a separate shortening motion.

The arrangement employed at the present time for obtaining the differential speed of the bobbin and bobbin-lifter in the slubbing, intermediate, and roving frames, is Houldsworth's ingenious and successful Differential Motion, which was introduced in 1826, and is shown in Fig. 18, Plate 76. It consists of three portions, the first of which is driven at a constant speed, and drives the spindles and fliers; the second is driven from the first at a speed varying in proportion to the increase of diameter of the bobbins; and the third portion, from which the bobbins and bobbin-lifter are driven, receives a differential motion compounded of the other two, and therefore also varying with the increasing diameter in winding. The shaft K being driven at a constant speed by the driving strap over the pulley L imparts a uniform speed to the spindles and fliers by the pinion M, which is fast upon the shaft. The pinion N driving the bobbins and bobbin-lifter runs loose upon the shaft, and is driven through the differential bevil gearing O by the bevil wheel P keyed upon the shaft K. The two bevil wheels O O, through which the differential motion is obtained, are centred in the disc wheel Q running loose upon the shaft K. If the disc wheel were held stationary, the pinion N would be driven through the wheels O O at the same speed as the wheel P, but in the contrary direction,

and would therefore drive the bobbins at the same speed as the spindles; but if the disc wheel Q were made to revolve upon the shaft K at half the speed of the wheel P, but in the contrary direction, the pinion N driving the bobbins would run at double the speed of the wheel P. If therefore the disc wheel Q be driven at an intermediate speed, and this speed be also made to vary in proportion to the increasing diameter of the bobbins, the pinion N will receive and impart to the bobbins and bobbin-lifter a differential speed, which also will vary in the ratio of the diameter of the bobbins. This object is obtained by driving the disc wheel Q through the pair of regulating cones R and S, which are parallel but reversed end for end in respect to each other; the first cone R is driven at a constant speed direct from the shaft K, and drives the second cone S through the strap T, which is made to travel gradually from one end of the cones to the other. Hence the disc wheel Q, which is driven by the second cone S, runs at a varying speed depending upon the position of the strap upon the cones; and by making the strap travel along the cones at a rate corresponding with the increasing diameter of the bobbins, the speed of revolution of the bobbins is accurately proportioned to their diameter so as to give the required uniformity in surface speed throughout the winding. The travel of the strap T is effected by a rack motion I and ratchet-wheel J, Fig. 17, each vertical reciprocation of the bobbin-lifter releasing the ratchet-wheel J one tooth, and allowing the strap to be drawn forwards the corresponding distance along the cones R and S by the weight W constantly acting upon the strap-fork.

In the case shown in Fig. 18, it will be seen that the speed of the first cone R is one half that of the driving shaft K; and the speed of the disc wheel Q is one fifth that of the second cone S, and its rotation is in the contrary direction to the driving shaft K. The diameters of the cones being 6 inches at the large ends and $3\frac{1}{2}$ inches at the small ends, when the strap is at the end U, as shown by the dotted lines, the ratio of speed of the disc wheel Q to the driving shaft K is $\frac{1}{2} \times \frac{6 \cdot 0}{3 \cdot 5} \times \frac{1}{5} = \frac{1}{6}$ nearly; that is the disc wheel makes one revolution for every six of the driving shaft, and in the contrary direction; and therefore the bobbin-pinion N makes

8 revolutions for every 6 of the flier-pinion M. Similarly when the strap is at the end V of the cones, the ratio of speed of the disc wheel to the driving shaft K is $\frac{1}{2} \times \frac{3 \cdot 5}{6 \cdot 0} \times \frac{1}{8} = \frac{1}{16}$ nearly; that is the disc wheel makes one revolution for every sixteen of the driving shaft, and in the contrary direction; and therefore the bobbin-pinion N makes 18 revolutions for every 16 of the flier-pinion M. Hence the ratio of speed of the bobbin-pinion to the flier-pinion is 32 to 24 in the first case and 27 to 24 in the second; and the total reduction of speed of the bobbins, whilst the strap travels along the entire 30 inches length of the cones, is 5-32nds or 16 per cent. of their original speed, which is the range of variation required to allow for the increasing diameter of the bobbins in winding.

The differential motion affords the means of obtaining this delicacy of adjustment with a compact and easily worked apparatus; and by virtually magnifying the range of variation required avoids the use of cones with too small a taper for good working. The arrangement shown in Fig. 18 is for the case of the bobbin running in advance of the flier, when the speed of the bobbin has to be reduced as its diameter increases in winding; and the action of the differential motion is exactly similar in the converse case of the bobbin following the flier, the only difference being that the disc wheel Q must then be made to rotate in the same direction as the driving shaft K, instead of in the contrary direction. As the advance of the driving strap T along the cones is a uniform amount at each reciprocation of the bobbin-lifter, the driving cone R requires to be shaped with a concave outline and the driven cone S with a corresponding convex outline; since the absolute increase made in the diameter of the bobbin by each successive layer of roving bears a continually diminishing ratio to the increasing diameter of the bobbin, requiring the variation of speed therefore to be effected also in a continually diminishing ratio.

Arkwright's Can Frame was the first machine invented of the class now comprising the slubbing, intermediate, and roving frames above described; it consisted of a row of revolving cans, into which the sliver was delivered from a set of drawing rollers similar to those used in the drawing frame. The cans were driven by bands

passing round pulleys at the bottom, and the top of each can was contracted into a tubular neck, forming a bearing, which ran in a bush in the framing of the machine, and through which the sliver from the drawing rollers was delivered into the can in irregular coils. There were three or four pairs of drawing rollers in this can frame, and two of the slivers from the drawing frame being fed into the rollers were doubled and drawn into one of about eight times the original length, which was delivered into the can; and when the can was full the sliver or roving was taken out, and wound upon bobbins by a separate winding machine. As the sliver was merely delivered into the can of the can-frame through the central orifice at the top, it did not receive any regular coiling into the can, and the amount of twist imparted to it was therefore irregular; the can made about 100 revolutions per minute, and the sliver being delivered from the rollers at about 16 feet per minute, the average twist amounted to only about $\frac{1}{8}$ turn per inch of roving. Hence the delicate roving was liable to be injured in being conveyed to the winding machine.

The next step in improvement was made by substituting spindles, fliers, and bobbins, in place of the cans in the can-frame; and the spindles and fliers being driven at a constant speed, the differential motion was applied for driving the bobbins and bobbin-lifter at the varying speed required by the increasing diameter of the bobbins. The differential speed was obtained by means of a cone drum, or friction pulleys, or an expanding drum, which were made to slide endways upon the shaft driving the bobbins, the distance of sliding being regulated by a ratchet-toothed rack with a paul working into it; the teeth of the rack were cut to suit the fineness of the roving to be wound, and hence any change in the size of roving made for different counts of yarn necessitated a change of rack. This was found very inconvenient, and was at length obviated by the introduction of Houldsworth's differential motion already described, which requires only a single rack and pinion of uniform pitch, with ratchet wheels of varied pitches for giving motion to the rack-pinion; so that for a change in the fineness of the roving it is only necessary to change the ratchet wheel, which is readily effected and

is much more convenient than having to change the rack. When this form of the differential motion was first applied, one cone drum only was used, with counter pulleys, and a weighted pulley for keeping the strap tight; but latterly the two cone drums shown in Fig. 18 have been used instead, made with corresponding concave and convex surfaces so that the strap continues equally tight in all positions.

Spinning.—The final operation of spinning into threads the rovings delivered from the roving frame has been the subject of so great an exercise of inventive abilities, and has undergone so many practical improvements in detail down to the present time, that it is impossible to do more in the present paper than notice briefly the more important steps which have led to the remarkable perfection attained in the self-acting mules now employed for this purpose.

In the practical working of Arkwright's spinning machine and Hargreaves' spinning jenny, Figs. 1 and 2, Plate 68, it was found that the rovings and threads produced were both coarse and uneven, only fit for the manufacture of quiltings, and poorly adapted even for that purpose. A great improvement in this respect was effected in 1779 by Samuel Crompton's spinning machine or "mule," which was a combination of Paul's or Arkwright's spinning machine and Hargreaves' jenny, combining the drawing roller arrangement in the former with a modification of the sliding crossbar and spinning spindles in the latter. In this machine the spindles were placed in a moveable carriage, which had a stretch or run of about 54 inches; and the rovings delivered from the drawing rollers in a soft state were further drawn by the spinner in pulling the carriage backwards from the rollers, and completely twisted by the receding spindles, ready for being wound upon the spindles during the run-in or return traverse of the carriage and spindles. In the spinning jenny each successive length of the rovings was held by the clasp on the sliding crossbar, and the stretching of the rovings was done entirely by drawing back the crossbar by hand from the spindles; and in Arkwright's machine

the stretching was performed entirely by the rollers: but in Crompton's mule the stretching was accomplished partially by the drawing rollers, when the carriage and spindles began to recede from the roller beam, and partially by the continued run-out of the carriage after the rollers had been stopped. The rollers were stopped when the carriage had receded nearly the length of its run, and they then acted as a clasp to hold the threads during the completion of the stretching and twisting.

Crompton's first mule contained about thirty spindles; and the threads spun by it were far superior in regularity, strength, and fineness, to any ever spun before. They realised about double the prices obtained in 1743 for the same counts of yarn spun by other machines, and must therefore have been very superior in quality, having been produced much more cheaply; and in order to show what could be done with the mule, small quantities were spun as fine as No. 80, which is such a quality of thread that 80 hanks of 840 yards each weigh together 1 lb. The adoption of these mules extended so rapidly that in 1811, thirty-two years after the first was made, there were 600 mills containing 4,209,000 spindles working on this plan, and only 310,500 spindles on Arkwright's plan, and 155,900 spindles on the spinning-jenny plan.

Many of the principal movements however in the working of Crompton's mule still required to be performed by hand by the spinner, the same as in the previous machines. This was the case with the backing-off motion, and with the working of the two faller wires, a second or counter-faller having now been added underneath the threads, which was lifted for the purpose of taking up the slack in the threads after the backing-off, the first faller being depressed for guiding the threads upon the cops during the winding. The speed of the spindles also required regulating by hand during winding, so as to correspond with the increasing diameter of the cops formed on the spindles, and to suit the conical shaped ends of the cops. Great skill was therefore necessary on the part of the spinner, in order to make the cops regular in shape, size, and hardness, suitable for transport and for being uncoiled without waste. To supersede this skilled labour and render the mule

self-acting was therefore the great aim in the subsequent improvements.

In 1818 the entire operation of winding up the spun threads into cops on the spindles was rendered altogether self-acting by Mr. William Eaton. This involved both a self-acting method of performing the backing-off, which has to be done at the conclusion of the twisting of each stretch, before the winding begins; and also a self-acting arrangement in connection with the faller-wire, for guiding the threads regularly upon the cops during the winding, and a self-acting contrivance for regulating the speed of the spindles according to the increasing size of the cops.

The arrangement of Eaton's Backing-Off Motion is shown in Figs. 19 and 20, Plate 77. The main shaft or "rim shaft" A, from which the driving motion of the spindles in the travelling carriage is derived, is itself driven in the forward direction during the twisting, and again during the winding, by the driving strap running on the fast pulley B, as shown by the dotted lines in Fig. 20. The loose pulley C communicates a slow motion through intermediate pinions to the wheel D revolving loose upon the shaft A but in the contrary direction; and at the other end of the shaft A is a corresponding wheel E fast upon the shaft. The two toothed sectors FF are keyed upon a shaft G, which is carried in the rocking frame H; and the weight K on the rocking frame is constantly acting to draw the sectors back, out of gear with the wheels D and E; while the sectors themselves are only partly counterbalanced by the second weight L, and are ready to fall down into gear with the wheels as soon as the catch I, by which they are held up out of gear, is released. When the twisting of the threads is completed, the driving strap is shifted to the loose pulley C, and the forward motion remaining in the shaft A is arrested by a friction break carrying a ratchet wheel, which is caught by a hook falling into gear at the moment of reversing the strap. The pull upon this hook extends a spiral spring, the recoil of which is made to release the catch I; and the sectors F falling into gear with the wheels D and E, a backward motion is then communicated

to the shaft A from the loose pulley C running forwards, whereby the spindles are made to turn backwards through the few revolutions necessary for backing off the spiral coils of thread at the top of the spindles, preparatory to winding. As the form of cop employed was a simple cone, increasing in height at the same time as in diameter (as shown in Fig. 21), the length of the spiral coils that require backing off at the top of the spindles becomes less with the increasing height of the cops on the spindles, and the number of backward turns in the backing-off has therefore to be gradually diminished as the cops approach completion; this is effected by an adjustable stop underneath the sectors F, which is gradually elevated in proportion to the increasing height of the cops. This stop is connected with a lever catching against a stud at the lower extremity of the arm H of the rocking frame; and the downward movement of the sectors F, while in gear with the wheels D and E, depresses the stop until at length the arm H is liberated; the weight K then withdraws the sectors out of gear, whereby the backward motion of the shaft A is stopped. By then shifting the driving strap to the fast pulley B, the shaft A is again driven in the forward direction, and the threads previously spun are wound up on the spindles as the carriage runs inwards. The pin J fixed upon the carriage, travelling inwards in the direction of the arrow, now comes in contact with the tail of the lever M, and lifts the sectors up again into their highest position, in which they are retained as before by the catch I at the other end of the lever M; and when the run-in of the carriage is nearly completed, the same pin J comes in contact with the tail of a second lever N, bearing against the extremity of the arm H of the rocking frame, whereby the sectors are thrown forwards again in readiness for the next time of backing-off.

Eaton's Faller Motion is shown in Fig. 21, Plate 78, and was almost identical with that in use at the present time, the difference being that the faller wire A was depressed by a weight B, instead of as in the present mules by a chain passing round a pulley upon the faller shaft C. The direction of the run-in of the carriage D carrying the spindles and cops E is shown by the arrows; and

during the run-out in the opposite direction the weight B is held up in the position shown, by the catch F holding the tail of the lever G. This catch is withdrawn by the downward movement of the sectors in the backing-off motion, and the weight B then brings the front end of the lever G down upon an arm on the front side of the faller shaft C, depressing the faller wire A upon the threads H. The roller I, carried upon an arm on the back of the faller shaft, is thus brought up against the pin J fixed in the parallel-motion bar K, and is "locked" by the latch L; so that by the vertical movement of the bar K the faller wire A is raised and lowered during the winding of the threads, for guiding them upon the cops from end to end. The reciprocation of the bar K is obtained by its bottom end resting upon the shaper fusee or long tapered cam M, which is driven by the pinion N from the toothed wheel O travelling along a rack P fixed upon the floor. As soon as the carriage has begun to run in, the weight B is lifted off the faller and raised again to its original position by the tail R of the lever coming in contact with a fixed stop S. When the carriage arrives at the end of its run-in, the sliding bolt T coming against a fixed stop pushes back the latch L, and unlocks the roller I; and a balance weight upon the back of the faller shaft C raises the faller wire A clear off the threads into the extreme position shown by the dotted lines. For regulating the shape of the cop as its size increases, the shaper fusee M is gradually traversed endways along its shaft N by the rack and pinion U driven by a worm wheel from the ratchet V, which is turned round one tooth at a time by the lever W coming against a stop X fixed on the floor at each end of the run of the carriage.

In 1825 further improvements were introduced by Mr. Maurice de Jongh, the backing-off motion being driven by a rack instead of by sectors; and with the backing-off was combined the process of putting down the faller wire to the required part of the cops for the commencement of the winding. The working of the faller for guiding the threads during winding was effected by an arm on the back of the faller shaft, carrying a roller, which travelled along a template or "copping rail" extending the whole length of the

stretch. The upper edge of this copping rail was shaped according to the form of cop required, and the entire rail was gradually lowered by a regulating screw at each end as the cop was built up. The winding of the threads on the cops was done by employing a slack strap or friction strap for driving the main shaft or "rim shaft" of the mule, during the run-in of the carriage; and this strap was tightened by a weight and two friction pulleys pressing against it, the weight being adjusted so as to make the strap drive or slip as required for keeping the threads in proper tension.

It was also in 1825 that the late Mr. Richard Roberts' Self-Acting Mule was first brought out, which, with the addition of further improvements subsequently introduced by himself and others, is the form of self-acting mule almost universally employed at the present time for spinning cotton. In this mule the faller wire was for the first time put down by the agency of the "rim shaft" or main driving shaft of the machine, during the time that the shaft is turning the reverse way for backing off.

The arrangement of Faller-Wire Motion, as employed in the present spinning mules, is shown in Figs. 22 to 25, Plates 79 and 80. A is the top-faller arm, which is made of the sickle shape shown in the drawing for the purpose of enabling it to put down the faller wire to the bottom of the cops J, without the arm itself being required to pass down between the cops, so as to save room in the length of the mule. On the front of the faller shaft I is keyed the sector C, and a chain D attached to the sector passes round the pulley E to a snail F upon the shaft of the tin roller, which is a long hollow cylinder made of tin, and driving by separate cords the whole row of spindles T. The snail F is geared to the tin roller by a ratchet clutch, with the teeth set so as to engage only when the tin roller is driven the reverse way for backing off, as shown by the arrow in Fig. 23. Whilst the tin roller is running forwards during the spinning, and again during the winding, in the direction shown by the arrow in Fig. 22, the snail F is not in action; but as soon as the carriage G of the mule has run out to the end of the stretch, as shown in Fig. 23, the tin roller is turned through

part of a revolution in the reverse direction, as indicated by the arrow, sufficiently for unwinding the coils in backing off; and the snail F then comes into action and winds up the chain D, thereby bringing the top faller-wire A down upon the threads W and depressing them towards the bottom of the cops. On the back of the faller shaft I is fixed the curved arm B, against which bears the vertical locking bar H; and when the arm B is lifted by the depression of the faller A, its extremity is caught by the recess in the bar H, which is thrown forwards by the bell-crank lever K, as shown in Fig. 24; the tail of this lever having been brought, by the run-out of the carriage G, under the corresponding bell-crank L fixed in the end frame of the mule, has previously extended the spiral spring attached to the bell-crank L, Fig. 23, the recoil of which throws the locking bar H forwards as soon as the arm B is sufficiently raised, Fig. 24. The pulley E is carried on a rocking lever R, the tail of which presses against the stop S in the end frame of the mule during the time that the chain D is depressing the faller, Fig. 23; but at the moment when the locking bar H is thrown forwards to lock the faller arm B, the stop S is lowered, as shown in Fig. 24, clear of the tail of the lever R, allowing the pulley E to yield to the further pull of the chain D until the reverse motion of the tin roller in backing off is stopped; by this means the snail F, Fig. 23, is prevented from depressing the faller wire A beyond the required distance down the height of the cop.

The faller being thus locked, the carriage G begins to run in, in the opposite direction to that indicated by the arrows in Fig. 22; and while the spindles wind up the threads on the cops, the faller wire is gradually allowed to rise by the locking bar H running down the inclined copping rail M, the curved arm B being kept constantly pressed home in the notch of the locking bar, by a counterbalance weight or spring acting on the back of the faller shaft I to raise the faller A. The length of the stretch or run-in of the carriage G is 63 inches, which is therefore the length of thread to be wound upon the cop J at each time of winding; and this whole length of 63 inches of spun thread in each stretch is wound upon the cop during each stroke of the faller wire. The mode of building up the

cop in successive stages is shown half full size in Fig. 26, Plate 81; and in order to allow for the increasing diameter of the cop, the successive layers of thread are wound upon it in more open coils as the size increases, as indicated by the dotted lines, which is effected by gradually increasing the range of the faller wire; at the same time the ends of the cop are made of the conical form shown in the drawing. The length of range or "chase" of the faller wire at the commencement of the cop upon the bare spindles is only from A to B; but this is gradually increased until the cop has attained its full diameter C C, when the length of range is from C to D; after which the range is slightly diminished again to the length E F in finishing the cop. For the purpose of obtaining the requisite motion of the faller wire for giving these successive shapes to the cop during the winding, the extremities of the copping rail M, Fig. 22, are supported on the two sliding wedges N and O, which are kept at an invariable distance apart by a connecting rod. In commencing the winding of a set of cops upon the bare spindles, as shown at A B in Fig. 26, the copping rail is set at the top of the wedges and is at its smallest inclination; and after each successive layer has been wound on, the two wedges are slided from under the rail by a traversing screw worked by a ratchet-wheel, which is advanced one or more teeth during each run-out of the carriage G, Fig. 22. By this means the copping rail M is gradually lowered at both ends, and at the same time its inclination is increased by the outer wedge N being made with a rather smaller angle at the top than the inner wedge O, for the purpose of forming the cop with a more gradual taper at the top than at the bottom, as shown in Fig. 26. This increase of inclination continues until the cop has attained its full diameter C C and has assumed the shape A C D; after which the inclination slightly decreases again until the cop is completed to the finished shape A C E F, by the latter part of the outer wedge N being made slightly steeper than the corresponding portion of the inner wedge O, as shown in Fig. 22. The inner end of the copping rail being the lowest, the winding of each stretch leaves off at the top; and at the commencement of winding each stretch the faller wire puts down the thread to

the point at which the winding of the new layer is to be started, about three coils being wound on during the descent of the faller, as indicated by the spiral dotted line from F to E in Fig. 27, and the remainder during the rise of the faller. When the spindles arrive at the rollers P, as shown in Fig. 25, having wound up the 63 inches stretch of threads, the stop U pushes back the locking bar H, thereby releasing the faller A, which immediately rises clear of the threads W.

The counter-faller wire is carried by the arm V from a second shaft behind the top-faller shaft I, and during the winding it bears up constantly against the underside of the threads W, as shown in Figs. 23 and 24, with a slight pressure from a counter-balance weight or spring acting on the shaft, so as to ensure keeping the threads in proper tension; during the spinning the counter-faller is held up just beneath the threads, but without touching them, as shown in Fig. 22. The arm V of the counter-faller is curved as shown in the drawing, so as to reach over the shaft I of the top faller, and also to avoid passing down between the cops; and the curved arm B on the back of the top-faller shaft I is shaped so as to clear the shaft of the counter-faller. The height of the counter-faller wire is employed as a means of regulating the speed of the spindles in winding, in the manner afterwards explained, so as to avoid the occurrence of any slack in the threads.

Roberts' Backing-Off Motion as employed in the present mules is shown in Fig. 28, Plate 81, which is a plan of the main driving shaft or "rim shaft" A of the machine, carrying the large "rim wheel" Z or double-grooved pulley driving the whole of the mule spindles by the endless cords X X, Fig. 22, passing round the pulleys Y Y. On the boss of the loose pulley B is a pinion C, which through a train of intermediate wheels D D drives in the reverse direction and at the required slower speed the spur wheel and friction cone E, also running loose upon the shaft A and sliding longitudinally upon it. This friction cone engages in a corresponding hollow cone inside the fast pulley F; and when the driving strap is shifted from the fast pulley F to the loose pulley B for the purpose of backing off, the friction cone is also brought up against the fast

pulley, thereby first arresting by friction the forward motion of the driving shaft A, and then giving it the reverse motion for backing off.

Roberts' Winding Quadrant for regulating the winding of the threads, by diminishing the speed of the spindles in proportion as the diameter of the cops increases, is shown in Fig. 29, Plate 82. This very ingenious contrivance has never been superseded, and is employed in almost every self-acting mule at the present day. The quadrant A turns upon a fixed centre C in the frame of the mule, and a pinion B gears into it, which is driven by a band and pulley receiving motion from the traverse of the carriage G, the arrows indicating the direction of motion during the run-in of the carriage. The grooved arm D of the quadrant contains a double-threaded screw, by which the sliding nut E is traversed outwards from the centre of motion C towards the extremity of the arm D. When the carriage is at the outer end of its stretch, the arm D stands inclined 12° outwards from the vertical, as shown by the dotted lines; and during the run-in of the carriage it turns inwards through an arc of 90°. A chain F attached to the nut E is coiled round a drum H inside the carriage G, and as the carriage recedes from the quadrant arm during the run-in the chain thus causes the drum to rotate, and thereby drives the spindles T through the intervention of the tin roller I geared to the drum H. At the commencement of a set of cops, the nut E is at the bottom of the quadrant arm D, nearest to the centre of motion C, as shown dotted; and the number of revolutions then given to the drum H by the uncoiling of the chain during the run-in of the carriage is nearly as many as if the end of the chain at the nut were held stationary, and is sufficient to wind up on the bare spindles the length of threads spun in one stretch.

As the cops increase in diameter from their original size A B to their full diameter C C, Fig. 26, the nut E is gradually advanced outwards along the quadrant arm D, Fig. 29, so as to increase its arc of motion and thereby diminish the number of revolutions of the drum H and the speed of the spindles T. This advance of the nut is obtained from the counter-faller V bearing against the underside

of the threads W during the winding. The depression of the counter-faller towards the lower part of the cop J brings down the end of a governing lever upon a horizontal strap, which passes round a pulley on the headstock of the mule and round another on the centre shaft C of the quadrant; and on this shaft is a bevil pinion gearing into a second bevil pinion on the end of the double-threaded traversing screw in the arm D; so that when the governing lever is depressed upon the strap by the counter-faller, the forward motion of the lever as the carriage runs in drags the strap along with it by friction and turns the shaft C forwards, sliding the nut E outwards towards the circumference of the quadrant. At the moment when the backing-off motion has ceased and the carriage begins to run in for winding up the stretch of thread spun, as shown in Fig. 24, the counter-faller wire V is at its highest working position, compensating for the additional length of thread that has been uncoiled from the top of the spindle in backing off after the spinning of the stretch was completed. The nut E however, Fig. 29, is still at the same distance from the centre C of the quadrant as it was at the conclusion of winding the previous stretch; and therefore, as the diameter of the cop is now greater by winding the new layer of thread outside the previous one, the winding of the new stretch commences rather too fast, and begins at once to take up the length of thread given out in the backing off. The counter-faller V is thus depressed, and by means of the governing lever slides the nut E further out from the centre C, until the speed of winding is sufficiently diminished to allow the counter-faller to rise again high enough for lifting the governing lever off the strap. It will be seen that, in consequence of the arm D describing the quadrant of a circle, the horizontal motion of the nut E in the winding of each stretch is greatest at the commencement of the winding and gradually diminishes as the carriage runs in; and the effect of this is that the speed of winding is gradually increased towards the end of each stretch. By this means the threads are wound uniformly upon the cops, with an equal degree of tightness throughout.

The whole mule is driven by a strap $3\frac{3}{4}$ inches broad, running over the fast pulley F, Fig. 28, on the rim shaft A, and travelling at about 1670 feet per minute or about 19 miles per hour. The driving power required is about 1 indicated horse power per 230 spindles, or $4\frac{1}{4}$ horse power for each mule containing 1000 spindles. The speed of the endless cord X passing round the rim wheel Z, Fig. 22, is 2640 feet per minute or about 30 miles per hour. The carriage of the mule makes 3 to $3\frac{1}{2}$ double journeys out and home per minute, the length of stretch being 63 inches; but the velocity varies at different parts of the traverse, the carriage being taken in by a pair of scrolls in the centre of the machine, and drawn out by three spiral grooved pulleys keyed upon a shaft running the entire length of the mule, one pulley being in the middle of the shaft and one at each end. The length of the carriage being upwards of 100 feet, a parallel motion is required for keeping the carriage straight; and this is obtained by a horizontal traversing pulley at each end of the carriage, traversing along fixed cords and thereby made to revolve; and these two pulleys being also coupled together by a crossed cord are compelled to revolve at the same rate, and consequently cause each end of the carriage to travel at the same rate. There are three pairs of drawing rollers P, Fig. 22, by which the rovings are drawn about 8 times before being delivered for spinning. The last pair of rollers delivers the rovings at a speed of 26 feet per minute, until the carriage G has run out the 63 inches length of stretch, when the rollers are stopped, and hold the threads fast during the winding up as the carriage runs in again. The actual length of roving delivered by the last pair of rollers for each stretch of 63 inches is about 61 inches.

The spindles make about 1260 revolutions in twisting each stretch of 63 inches, thus putting about 20 twists per inch into the threads; and the total time occupied is about $12\frac{1}{2}$ seconds. In winding up the threads, as the total length to be wound up remains constant, namely 63 inches, the number of revolutions is diminished in each successive stretch according to the increasing size of the cop, from about 70 revolutions at the commencement to 23 revolutions at the full diameter of the cop, with cops of an average size winding

an average number of yarn, such as No. 32, which is such a quality that 32 hanks of 840 yards each weigh together 1 lb.; the time of winding each stretch is about $3\frac{1}{2}$ seconds. The velocity of the spindles is about 390 revolutions per minute in winding, and in twisting the speed ranges from 8000 down to 3000 for coarse work, a common average being about 6500 to 7000 revolutions per minute. In backing off the velocity of revolution is about 1-20th of that in twisting. The direction of rotation of the spindles is the same in twisting and in winding, and the thread is wound on in a right-handed spiral when spinning twist, and left-handed when spinning weft. Fig. 27, Plate 81, shows full size the conical form of the top of the spindles for the purpose of letting the thread slip off freely at each revolution in twisting; and the two lines G and H show the extreme inclinations of the thread to the spindles during the twisting. The larger angle shown by the dotted line G, when the spindles are nearest to the drawing rollers, is about 145°; and the smaller angle shown by the full line H is about 105°, when the spindles are at the outer extremity of the stretch. The spindles themselves are inclined inwards towards the drawing rollers at an angle of about 12° from the vertical, as shown in the drawing.

In a mule invented by Mr. John Robertson in 1834 and brought out with other improvements in 1839 by Mr. Smith of Deanston, the chief feature was the use of a mangle wheel for performing the principal motions and changes, including a method of increasing the amount of twist put into the threads during the last few inches of each stretch. The mule of Mr. James Potter also possesses some features, which, although they have not been largely adopted, have much merit in them. The carriage is moved in and out by an arm travelling through half a revolution, so that the motion begins and ends slowly and is quickest at the middle of the stretch. The winding on is effected by an adjustable conical drum, the larger end of which is of the proper size for winding upon the bare spindles, and the smaller for the full cops; the drum is traversed longitudinally on its shaft by a screw of differential pitch, to the nut of which is attached the winding chain that coils on the drum; and the position of the chain on the drum is changed rapidly at the

commencement of a set of cops, and more slowly as they fill up. This spiral cone drum was subsequently replaced by a contracting spiral pulley, which at full diameter drove the bare spindles, and gradually contracted as the cops approached completion.

The number of spindles in the self-acting mules has been gradually increased, until at the present time many mules contain 1000 spindles each. One pair of these mules requires the attendance of only one man and two boys, for cleaning the machines, setting in the rovings, attaching the broken threads, taking off the cops when full, and starting the machines to work again. In spinning No. 32 yarn (in which the weight of 32 hanks, each containing 840 yards, is 1 lb.), the production of the pair of mules per week of 60 hours is 45,000 hanks, or 21,477 miles per week, weighing 1406 lbs. The floor space occupied by one of the mules containing 1000 spindles is about 116 feet by 10 feet, leaving about 4 feet for passages at the ends of the mules in the modern mills of 120 feet width. The cost of a modern cotton mill for spinning No. 32 yarn, including building, machinery and accessories, steam engine and shafting, with fire-proof floors in the scutching and carding rooms and timber floors in the spinning rooms, averages 18*s.* per spindle; and one mill was built, during the cotton panic caused by the American war, for 15*s.* per spindle.

The progress made in cotton manufacture during the last century is strikingly shown by the following comparison between the years 1760 and 1860:—

	1760.	1860.	
Total value of cotton yarn produced	200,000*l.*	85,000,000*l.*	425 times greater.
Weight of cotton imported	3,870,000*lbs.*	1,083,009,000*lbs.*	280 ,, ,,
Value of 1 lb. of No. 42 yarn . . .	10*s.* 11*d.*	11*d.*	12 times cheaper.
,, ,, No. 100 ,, . . .	38*s.* 0*d.*	2*s.* 6*d.*	15 ,, ,,

As an illustration of the present extent of the manufacture, it may be mentioned in conclusion that the number of spindles employed at the present time in the cotton manufacture of Great Britain exceeds 36 million; and taking them as spinning on the average No. 32 yarn, when each spindle produces per week 22½ hanks of 840 yards each, there is a regular production from the

whole of 64 million miles of yarn per day of 10 hours when in full work, or a length of thread equal to more than four times round the earth every minute.

The PRESIDENT remarked that the great extent of the advance effected in the production of cotton thread by the employment of the modern machinery was clearly illustrated by the particulars given in the paper just read as to the rate of spinning that was now attained. In India the old system of hand spinning still prevailed, as it had existed for hundreds of years past, the whole process being performed by the fingers; but from the particulars given in the paper of the remarkable results now attained by the improvements in machinery, the amount of thread spun by one of the present self-acting mules was as great as could be produced by 3000 hand spinners he believed, a pair of these mules requiring only the attendance of three persons, each of whom thus did as much work as 2000 could accomplish without machinery.

Mr. B. FOTHERGILL considered they were greatly indebted to the author of the paper for the clear account that had been given of the progress of cotton spinning, tracing the principles of the successive improvements from the first application of machinery down to the beautiful contrivances in use at the present time. The original machines of Paul and Arkwright, both the spinning machine, the carding engine, and the drawing frame, were fortunately all preserved now in the South Kensington Museum, having been obtained from Arkwright's family; they were in themselves of very great interest, and showed clearly that Arkwright and those who worked with him had a thorough practical knowledge of the nature of the fibre to be operated upon and the appropriate means to be employed. He was glad to hear it stated in the paper that the original invention of the principle of drawing by rollers was due to Paul, as the credit of the invention had until recently been given through mistake to others. It might perhaps not be generally known that the principle of Hargreaves'

spinning jenny was still adopted in spinning wool for the manufacture of cloth; only that instead of the roving of wool being held tight by a clasp, as in the original spinning jenny, a single pair of rollers was used, which delivered about 15 or 18 inches length of roving at a time to be twisted into thread, and the rollers were then stopped and the wool drawn out little by little by the carriage travelling along to the further end of the machine and twisting the rovings during the drawing. The principle on which this process was successful in producing a uniform degree of elongation throughout the length of the rovings was that wherever there was a thin place in the thread the greater portion of the twist ran into that part at first and thereby rendered it more difficult to be elongated than the thicker parts, which were thus drawn down in turn, and the production of an even thread was the result. The same principle was also adopted for spinning even the finer numbers of woollen yarn; but three pairs of rollers were then used, running at different speeds to aid in the drawing action and obtain greater uniformity of thread, instead of only a single pair.

Having assisted the late Mr. Roberts at the time of the invention of the self-acting mule, he remembered the introduction of the first of these machines at Mr. Birley's cotton mill in Manchester, and the great difficulties that had to be encountered from the opposition of the workpeople. Frequent breakdowns occurred at first, particularly of the cast-iron portions of the machine, which were accordingly replaced by wrought iron; and it was at length discovered that the continual damage to the machine was wilfully occasioned by the persons in charge of it, for the purpose of putting an end to its use. In spite of all opposition however the self-acting mule was successfully established, and was now universally employed in the cotton manufacture.

Mr. PLATT said he was indebted to his partners, Mr. Richardson and Mr. Spencer, for their aid in the preparation of the paper that had been read, the object of which had been not so much to enter into the details of particular machines, as to give a general account of the progressive steps of mechanical improvement introduced in the preparation and spinning of cotton. He had thought it

important to give prominence in the paper to the name of Paul, as the real originator of drawing by rollers, because it had hitherto always been customary through mistake to attribute this invention to Arkwright and Hargreaves. There was no question that the amount of mechanical ingenuity displayed during the last forty years in connection with cotton machinery was unparalleled in history; and the machine that was above all others the most interesting, and the one in which mechanical science had been brought most to bear, was the self-acting mule. A great many names were of course associated with the maturing of the many details in this machine and bringing it to its present state of perfection; but no one shone out so prominently as the late Mr. Richard Roberts, who first brought true mechanical principles to bear in the construction of the self-acting mule; and with the exception of details, the working of the machine was the same in principle at the present time that it had been when first introduced by him about 1825. Houldsworth was another whom it was necessary to mention particularly, because by the introduction of the differential motion he gave a character of perfection to roving machines which they never possessed before. The self-stripping carding engine now generally in use was originally introduced by Mr. Smith of Deanston; but it did not prove commercially successful until worked out into its present complete shape by Mr. Evan Leigh. There was little doubt however that the carding engine would find a great rival in the combing machine, which had been invented in France and recently introduced into this country for a different purpose; and though the machine was somewhat complex in its construction, and certainly quite distinct in principle from the carding engine, he believed it was destined to work a great revolution in the carding and stripping of cotton, and it was possible that combing might ultimately supersede carding altogether in the preparation of cotton. At present however the combing machine was comparatively in its infancy, so that it would be premature to enter into particulars respecting it; but he thought that on a future occasion it would afford good material for a separate paper on the subject.

Mr. RAMSBOTTOM enquired whether the drawing action by means of pairs of rollers running at different speeds was due to Paul, or whether he simply used a single pair of rollers.

The PRESIDENT replied that they were indebted to Paul for the three pairs of rollers running at different speeds, so as to produce the drawing action between each pair which constituted the important feature of his invention.

Mr. W. RICHARDSON mentioned that Paul was also the first who employed a revolving cylinder for carding, which had previously been done on a flat surface.

Mr. B. FOTHERGILL observed that Paul had gone beyond the mere substitution of a revolving cylinder in place of a flat carding table, as he had also taken the great step of adding the series of carding rollers round the circumference of the main carding cylinder, which had been subsequently embodied and more thoroughly worked out in the carding engine of Arkwright, and further improved by the addition of the doffing knives for clearing the carding teeth during working.

Mr. W. RICHARDSON remarked that the combing machine, which had been referred to as now being introduced for the preparation of cotton, was of particular value in connection with the great demand that had now sprung up for thread for sewing machines; a strong and clear thread was required without any breaks, and in order to produce this the longer fibres of the cotton were required to be separated from the shorter; and this was successfully accomplished by the combing machine.

The PRESIDENT moved a vote of thanks for the paper, which was passed, to Mr. Platt, and also to Mr. Spencer and Mr. Richardson.

The following paper, by Mr. John Frederic Bateman, of London, Engineer-in-Chief to the Manchester Water Works, communicated through Mr. William Fairbairn, was then read:—

DESCRIPTION OF THE MANCHESTER WATER WORKS.

By Mr. JOHN FREDERIC BATEMAN, of London.

The works by which the city of Manchester and its suburbs are now supplied with water were originally designed in 1846, and were commenced in the autumn of 1848; and the water was first introduced into the city at the end of 1850. Previously to this date the water supply had been gathered from various sources: for some twenty years the greater portion had been obtained from a limited tract of gathering ground within a few miles of Manchester; a small additional quantity had recently been procured from a well sunk into the new red sandstone at Gorton; and urgent deficiencies were made up by occasional supplies from the Ashton and Peak Forest Canals. The supply however was very inadequate and very impure. The present water supply is brought from the River Etherow, which divides the counties of Derby and Chester, deriving its supplies from the western slopes of the great chain of hills commonly called the backbone of England.

A general plan showing the drainage area and the entire course of the works to Manchester is given in Fig. 2, Plate 84; and Fig. 3, Plate 85, is a longitudinal section along the line of the works. The drainage ground lies nearly midway between Manchester and Sheffield, and extends over about 19,000 acres. It rises in parts to an elevation of about 1800 feet above the level of the sea, and about 1200 or 1300 feet above the deep and romantic valley of Longdendale, in which the main collecting reservoirs are situated, as shown to a larger scale in the plan Fig. 1, Plate 83. The district consists of the shales and sandstones which constitute the lower portion of the coal series, the upper millstone grit forming the cap of the steep escarpments on each side, while the lower

millstone grit, which may be said to separate the coal measure shales from the limestone shales, is found in the bottom of the valley. The water yielded by this geological formation is some of the purest in the world, being equal in general character to the water of Loch Katrine which supplies Glasgow. The spring water is especially brilliant, highly aerated, containing little or no foreign matter, and varying from about $1\frac{1}{4}°$ to $2\frac{1}{2}°$ of hardness according to Dr. Clark's scale, in which 1° of hardness is that corresponding to 1 grain of lime dissolved in 1 gallon of distilled water. The spring water is at all times most abundant, the district yielding much more than the usual quantity in proportion to the area from which the springs issue.

The average rainfall is about 50 inches per annum, and the average amount of water which may be collected about 40 inches, the net produce of three or four consecutive dry years being about 33 inches in each year. This quantity if wholly stored would afford a gross supply of about 39 million gallons per day; from which a certain stipulated guaranteed quantity has to be given as compensation to the mills on the streams interfered with, amounting to nearly 13 million gallons per day on the average of every day in the year; this leaves as the supply available for the city and its suburbs 26 million gallons per day. The quantity at present supplied is about 13 million gallons, so that there is water for double the population at the same rate of consumption.

Pure and beautiful as all the water is in dry weather and when unaffected by recent rain, the river and most of the principal streams are coloured by peat in floods and wet weather, especially in the summer and autumn months of the year. These circumstances determined several of the more important arrangements of the works. The average quantity of pure uncoloured water was more than sufficient for the wants of the city, but the actual amount was sometimes less than required and at other times too much. A system of separation was therefore adopted, by which the pure spring water, and the stream water when uncoloured, should either be taken direct to Manchester; or, when there was more than was wanted for the daily supply of the city, should be stored in reservoirs

set apart for the storage of pure water. The turbid or coloured water, being the water of floods, was to be stored in reservoirs specially allotted for the purpose; and after becoming comparatively pure by settlement and exposure to the atmosphere, it was either to be discharged into the river as compensation to the mills, or decanted off into the pure-water reservoirs for the supply of the city. The means adopted for carrying this object into effect were very simple and certain, and have proved perfectly successful. Each stream, whether large or small, separates itself by a simple arrangement, so that the pure water flows on direct to Manchester, or into the pure-water reservoirs, to be there stored for future use; and the turbid water flows into the turbid-water reservoirs or runs to waste down the river.

In Fig. 4, Plate 86, is shown the manner in which the separation of the water is effected in a large stream, the Crowden Brook. A weir A A is erected across the stream, with a passage B for water within the masonry beneath the top. In front or on the down-stream edge of the weir, a narrow transverse slot C opens into the passage beneath. When the stream is small, as indicated by the lower water line D D, or rather when not swollen by rain, and the water consequently perfectly pure, it drops through the slot into the passage B beneath, which communicates with a conduit to convey the water to Manchester or to the pure-water reservoirs. The slot C is constructed of such a width as to admit the whole stream, when it consists only of the pure water; but when the stream is swollen, as indicated by the upper water line E E, the velocity with which it passes over the weir is sufficient to carry it clear over the slot and down the face of the weir, into the ordinary river course or to the reservoirs for turbid water. Figs. 5 and 6 show the separating arrangement adapted to the case of a small stream, where the object is effected by a transverse slot C in a trough F crossing the pure-water conduit B. The water, when small in quantity and consequently pure, falling from an elevated ledge at the back of the slot, drops through the slot into the pure-water conduit B; but overshoots the slot when the quantity is large, and is then carried by the trough F in another direction.

The main impounding Reservoirs, shown in Fig. 1, Plate 83, are constructed in that beautiful part of the valley known as Longdendale, and are five in number. Three of them, namely the Woodhead, Torside, and Rhodeswood reservoirs, are constructed along the course of the River Etherow in the main valley, which they occupy for about 5 miles in length. The other two, the Arnfield and Hollingworth reservoirs, are placed on tributary brooks. The highest, the Woodhead reservoir, is at a level of 790 feet above the sea. The point at which the water leaves the lowest or Rhodeswood reservoir to be conducted to Manchester is about 13 miles distant from the city. To this point also is conducted all the spring water and pure water collected by the various conduits constructed for the purpose; and the joint volume of water is conveyed away by a common aqueduct* for the use of the city, as shown in Figs. 2 and 3.

This aqueduct is principally a covered conduit. It has a fall of 5 feet per mile, and passes under the Mottram ridge by a tunnel of about 3000 yards length, Fig. 3, and terminates in a reservoir at Godley near Hyde, about 8 miles distant from Manchester and 314 feet above the centre of the city. From this reservoir the water is conducted by a single line of cast-iron pipes of 40 inches diameter to two service reservoirs at Denton, about 4 miles from Manchester and 163 feet above the centre of the city; the average fall of the pipes from Godley to Denton is 43 feet per mile. The Denton reservoirs are used for the service of the higher parts of the city, while the old Gorton reservoirs, the lowest of which is 77 feet lower in level, are employed for the supply of the lower parts; and a pipe of 30 inches diameter is now being laid direct from the Godley reservoir to supply distant localities and various elevated suburbs, such as Pendleton, Broughton, Cheetham Hill, and Newton. From the Denton reservoirs to Manchester there is a line of pipes of 36 inches diameter; and a culvert of 4 feet diameter conveys a portion of the water to the old Gorton reservoirs, from which the lower parts of the city are supplied. From these latter reservoirs two pipes, of 24 and 18 inches diameter, convey the water to the city.

* (In Fig. 1 for "Line of Pipes" read "Line of Aqueduct.")

The total capacity of the five reservoirs in Longdendale is about 550 million cubic feet when full to the level of the overflow weirs, and their area about 400 acres. The heights of the embankments and the capacities of the several reservoirs are given in the following Table:—

Name of Reservoir.	Height of Bank.	Depth of Water.	Area of Reservoir.	Capacity of Reservoir.	
	Feet.	Feet.	Acres.	Cubic Feet.	Gallons.
Woodhead . . .	90	72	135	198,000,000	1,235,000,000
Torside	100	84	160	236,000,000	1,474,000,000
Rhodeswood. . .	80	68	54	80,000,000	500,000,000
Arnfield	67	52	39	33,600,000	209,000,000
Hollingworth . .	70	52	13	11,660,000	73,000,000
Godley		21	15	9,800,000	61,000,000
Denton No. 1 . .		20	7	4,800,000	30,000,000
——— No. 2 . .		20	6	3,700,000	23,000,000
Gorton Upper . .		26	34	19,500,000	123,000,000
——— Lower . .		29	23	16,000,000	100,000,000

The Manchester Water Works were at the time of their execution the largest works of the kind which had been constructed in this country, and in some respects the largest which had ever been constructed in any part of the world. Much therefore had to be specially considered, and nothing more so than the best form of the large valves, and the easiest mode of opening them under great pressure. There was little which then existed that could be advantageously imitated; everything had to be designed anew, with special reference to the work to be performed. In order to arrive at the best mechanical contrivance, public competition was invited upon a clear description of what was required and a short specification of certain conditions that were to be met. This resulted in many valuable suggestions, which were either adopted exactly as they were proposed, or modified and improved by subsequent consideration; and altogether a mass of information was in this way collected which could not perhaps have been obtained otherwise. It is but justice to say that, amongst the designs

for the larger apparatus, by far the best proposals and the best designs for the objects to be attained, taking all circumstances into consideration, were those received from Sir William Armstrong, who was accordingly the maker of all the large valves required for the works.

It was laid down as a principle that, whatever the size of the valve or the pressure under which it had to be worked, it should be so contrived as to be easily opened and shut by one man. No large valve then existing met this condition; and it frequently happened that a valve of no greater diameter than 24 inches, if it had to be worked under any considerable pressure, needed the combined power of half-a-dozen men. This requirement was met in all the large valves by dividing the valve into two and in some cases into three compartments, one of these being reduced to such a size as would be equivalent to a small valve, which could be easily opened by one man. This smaller division is first opened, and when it is open, the pressure behind the larger is to a great extent destroyed by the friction of the water flowing through the pipe beyond the valve; and the pressure is reduced to an amount equal to the extra head (never more than a few feet) required to pass the whole quantity through an aperture of the size of the small opening; or if the pipe beyond the valve merely requires filling, as soon as it is filled the pressure will be the same on both sides of the large valve. In either case the large valve can then be opened by one man. In Figs. 7, 8, and 9, Plate 87, is shown the construction of the 48 inch sluice valves employed for taking off the water from the large reservoirs, the whole valve being divided into the three compartments A, B, and C, which can be opened one at a time by the power of one man.

Another point of much importance was the adoption of means by which the water could be immediately shut off in case of the bursting of a large main; and this object was effected by the self-acting closing valve invented by Sir William Armstrong. Several of these valves were constructed and were brought into action on several occasions, when they proved most efficacious in arresting the escape of water and preventing serious damage. These valves were afterwards introduced in the Liverpool Water Works, and a

description of them is given in the paper on those works by Mr. Duncan at a former meeting of the Institution (see Proceedings Inst. M. E., 1863, page 174); they were also introduced in the Glasgow Water Works, as mentioned again in the paper by Mr. Gale on the subject (see Proceedings Inst. M. E., 1864, page 134). The great value of these valves is in the early stage of the works, when the pipes are first filled and subjected to the pressure they will ultimately have to sustain; but the valves should always be kept in working order, as pipes occasionally burst after years of work, without anything to account for the occurrence. In the Manchester Water Works some of these valves are discontinued, but others in suitable situations are kept in constant adjustment and are made to communicate with an alarum in the waterman's house, so that in the event of a pipe bursting and the valve closing he is instantly apprised of the accident.

In order to provide against the shock caused by stopping a large column of water many miles in length and flowing at a speed of several feet per second, a momentum valve opening outwards is placed upon the main behind each of the large stop valves and self-acting closing valves; and a description of this valve is also given in the former paper already referred to (see Proceedings Inst. M. E., 1863, page 175). These valves were also first used in the Manchester Water Works.

Self-acting valves called Reflux Valves are placed in the large pipes at the foot of all hills rising in the direction in which the water flows, for the purpose of preventing the water from flowing back again in the event of a pipe being emptied behind the valve by an accidental burst or otherwise. One of these valves in the 40 inch main is shown in Figs. 10 and 11, Plate 88, the flaps being made of leather, backed with cast-iron plates. The valves open with the current of water in the direction in which it ordinarily flows, as indicated by the arrow in Fig. 10, and close if the current is changed into the contrary direction.

A very important point in arranging water pipes on a large scale is the provision of ample means both for the rapid escape of

air from the pipes during the time they are being filled with water, and also for the subsequent discharge of the air which escapes from the water in its passage through the pipes and accumulates in the upper part of the bends formed by inequalities of the ground. Both of these operations, in order to be effectual, should be spontaneous or self-acting; and they are accomplished by means of the Self-Acting Air Valve shown in Fig. 12, Plate 89, which is mainly the invention of one of the writer's early assistants, Mr. Alfred Moore, to whom also is due the system of separating clear and turbid water as previously described. The construction shown in the drawing combines two air valves in a single casting, the large aperture A of 3½ inches diameter being intended for the escape of the large quantity of air while the pipes are being filled with water, and the small hole B of 1-8th inch diameter for the escape of the air accumulating in the pipes when full of water. The gutta-percha balls C and D forming the valves are each 5 inches diameter, and when the pipes are empty they drop into the positions shown by the dotted circles; but as soon as the water reaches them they are floated upwards, and close the apertures A and B, preventing the escape of the water. The ball D closing the small hole B is made of such specific gravity that its own flotation together with the small pressure corresponding to the area of the minute orifice B is only just sufficient to hold it up against the orifice; and consequently, whenever the flotation is diminished by the slightest accumulation of air at the valve, the ball falls away from the orifice and allows the air to escape; after which the orifice is again closed by the ball rising with the water.

A simple form of Hydrant or Fire-Cock has also been constructed, as shown in Figs. 13 to 15, in which a gutta-percha ball E is employed as the valve, being closed by the pressure of the water, as shown in Fig. 14, against a leather and vulcanised india-rubber seating. The cast-iron box G containing the valve is bolted to a vertical branch attached to the water main, and when not in use the outlet of the valve is closed by a loose stopper, and the whole is protected from injury by a cast-iron cover similar to the ordinary cover for protecting street cocks. For opening the fire-cock the top

cover is removed, and a standpipe H is attached through which the water is drawn off. The screwed collar I on the bottom of the standpipe fits under two lugs K on the top of the valve box, and the standpipe being then screwed down forms a water-tight joint by means of a leather washer on the bottom. A spindle J passes down the centre of the standpipe, working through a stuffing-box and screwed bearing at the top and through a guide below, and terminating at the bottom in a cup which fits the ball valve E; so that by turning the spindle by the handle at the top, the ball is depressed, and the water flows out through the standpipe H. This standpipe is attached in a few seconds; and as the opening and closing of the valve is effected gradually by the employment of the screwed spindle J, all concussion is avoided.

The sluice valves shown in Plate 87, for discharging the water of the large reservoirs in Longdendale, are fixed at the outer end of the outlet pipes, which are 48 inches diameter. They consist of three slides or compartments A, B, and C, Fig. 9, forming together a complete circular area, which may be opened either separately or together. Each slide is opened by means of a gun-metal spindle D passing through a stuffing-box, the upper portion being cut into a square-threaded screw working in a gun-metal bush fixed in headstocks. They are opened and shut by worm-wheel gearing, as shown at G in Fig. 16, Plate 90. One man can with some difficulty open one compartment at a time when the valve is under 70 or 80 feet of pressure. Two men can do the work easily; but at the two deepest reservoirs, the Woodhead and Torside, the operation of closing and opening is performed by the agency of a small turbine wheel, supplied with water for power from watercourses above the level of the reservoir. This is shown in Fig. 16, and to a larger scale in Fig. 17. The turbine H, of which a plan is given in Fig. 18, is geared by the spur wheel and pinion J to the worm-wheel gearing G working the valve spindles DDD; and the water for driving the turbine is admitted to it through the pipe K by a hand stop-valve at L in the supply pipe M. A self-acting slide-valve is placed at I, connected to levers worked by tappets upon the valve spindles D, whereby the water is shut off

from the supply pipe K of the turbine and turned into the waste pipe N, as soon as the main sluice valve is either fully opened or fully closed; this arrangement prevents the possibility of accident, should the attendant neglect to stop the turbine in time by the hand stop-valve L.

On each separate conduit for collecting spring water or for conducting water from the large impounding reservoirs to the city are placed Gauge Sluices, shown in Figs. 19 to 21, Plate 91, which act not only as stop-gates, but also as gauges for determining the quantity of water passing along each conduit. This is effected by gauging rods placed before and behind the sluice A, which is of definite dimensions; and by an index B which rises with the door of the sluice and indicates the extent that the sluice is opened. This index is shown to a larger scale in Figs. 22 and 23. By taking the difference in the level of the water behind and in front of the sluice, and the area of the opening through which the water is discharged, the application of the proper formula determined by experiment affords at all times the means of ascertaining the quantity of water passing through.

Where the water is finally discharged into the Godley reservoir it is passed through a basin A, Fig. 27, Plate 92, in one side of which a Gauge Plate B is erected, whereby the quantity of water passing is daily measured. This plate contains three rectangular openings, each 6 feet wide by 6 inches high, but with the approaches to the openings varied, as shown in the vertical sections Figs. 24, 25, and 26. The first opening, Fig. 24, presents a flat surface and knife-edge to the water flowing out through it in the direction shown by the arrow, and has a curve outside, which is the quadrant of a circle of $2\frac{1}{2}$ inches radius; the second opening, Fig. 25, is made with a curve of the same radius placed inside, so as to facilitate the discharge of the water; and the third opening, Fig. 26, has a double curve of the same radius, so as to present a curve to the water both in entering and leaving. These three different openings were arranged for the purpose of careful experiment, and the facts determined by the experiments made are very important. The

ordinary rule for determining the practical velocity of the discharge of water through an orifice in a thin plate is to multiply the square root of the head or pressure by the coefficient 5·1 or 5·4. The coefficients for velocity however, determined by the experiments made with these three openings, were 5·6 for the opening with the curve outside, 7·0 for the curve inside, and 7·6 for the double curve both inside and outside; the third opening thus giving a velocity nearly equal to the whole theoretical velocity due to the height of fall, for which the coefficient is 8·04. The openings in the gauge plate were entirely submerged on the inside, the depth of water in the basin A, Fig. 27, varying from about 1 foot to 4 feet above the centre of the openings; and the water had a free discharge on the outside, as indicated in Fig. 27, falling into a tank C of a given size, so that the quantity passing during any time was correctly measured.

Before the water leaves the Godley reservoir and again before it leaves the Denton service reservoirs, it is strained through copper wire-gauze strainers, the whole vertical area through which the water passes being about 800 square feet. The copper wire-gauze first tried consisted of 72 strands per square inch, but that was found to be too fine, as the apertures got rapidly closed, and the gauze became as tender as brown paper and was easily torn and broken. The gauze now used consists of copper wire made with 40 strands per square inch, which seems well suited for the purpose. No other filtration of the water is attempted or needed, as the water is always perfectly pure. The service reservoirs are from 18 to 20 feet deep, carefully paved on the slopes and bottom, and there is no vegetation in the reservoirs or in the conduits; and the only object of the strainers is to prevent extraneous floating matter in the water from passing into the pipes. The system of separation adopted as previously described wholly supersedes the necessity of filtration.

There remains to be noticed the means adopted for Gauging the Compensation Water that has to be given off to the millowners. This is shown in Fig. 28, Plate 93, which is a general plan of the arrangement, and Fig. 29 is a longitudinal section through the gauge basin and test basin; Figs. 30 to 34, Plate 94, show the

principal details to a larger scale. The water is first admitted into the masonry gauge basin A, in which the level is carefully regulated by means of sluices B. It then passes through two apertures in vertical gauge plates C, by which the quantity of water passing through may be accurately computed according to the pressure on the aperture, by employing the coefficient determined by the Godley experiments. In order to ensure a uniform discharge of water under a varying head, the gauge plates C, Figs. 30 to 32, are each fitted with a slide actuated by the float D, whereby the size of the gauging orifice is rendered self-adjusting, and varies inversely as the height of the water in the gauge basin A, thus giving a constant discharge. But in order to prevent the possibility of dispute, the water discharged from each gauge aperture C into the river below is carried by a trough E across a square test basin G, 30 feet square and 10 feet deep. In the bottom of each trough E, Fig. 30, is placed a tumbler I in a horizontal position, turning on an axis in the centre, and this tumbler ordinarily forms the floor of the trough and the water passes over it, as shown enlarged in Fig. 33. But on drawing back the hand lever H into the position shown by the dotted line, so that the extremity of the tumbler just clears the edge F of the trough, the tumbler is instantaneously reversed by the stream of water and turned vertically across the trough, where it is caught by the stop J, as shown in Fig. 34. In this position the water is discharged through the opening in the bottom of the trough into the test basin below, and at the same time the tumbler opposes an effectual barrier to its passing along the trough beyond the opening. The previous level of the water in the basin being noted, together with the time at which the stream is turned into it, the tumbler is again replaced at the end of a given interval in its original position shown in Fig. 33, by raising the stop J by the handle K so as to release the tumbler; the discharge of the water into the test basin is thus instantly arrested, and the water allowed to pass along the trough E as before into the river below. The height to which the basin has been filled during the time noted is then ascertained, and the quantity discharged is thereby accurately determined. This gauge is open to the inspection of all who are

interested in the supply of the compensation water, and the quantity discharged may at any time be tested by this means.

Mr. W. Fairbairn regretted that Mr. Bateman was prevented from being present at the meeting; and among the various features of the works that had been described in the paper just read, one of the most interesting he thought was the very simple arrangement for separating the turbid water from the pure in the streams supplying the storage reservoirs. In time of floods the water was found to be so turbid as to be unfit for immediate domestic use, and by the simple means of a narrow transverse slot across the bed of the stream the separation of the turbid water was effected with complete success, and the arrangement was entirely self-acting; the turbid water of the swollen stream overshot the aperture and passed on down the river, while the pure water when the stream had become reduced to its natural size dropped through the slot and was led away to the city or into special reservoirs. The plan of dividing the large sluice valves into three portions, so as to allow of opening at first a small portion only of the entire area, instead of having to open the whole valve at once, was found to answer very well, enabling one man to open and close the valves of the large mains, as the pressure was to a great extent relieved off the valve as soon as a small area was opened for the passage of the water. The self-acting air valves for allowing a constant escape of the air accumulating in the water pipes were found to act very efficiently, the smaller air-hole being opened by the descent of the ball whenever there was the slightest accumulation of air, and as soon as the air had escaped the ball rose again and closed the orifice, preventing any escape of water. The hydrant or fire-cock made with the gutta-percha ball valve was now coming into general use both in this country and abroad, on account of its convenience and great simplicity of construction.

Dr. Downing enquired about the sections of the apertures in the gauge plate at Godley reservoir (Figs. 24, 25, and 26), whether they

He understood also that syphons had been partially employed for the purpose, and enquired what had been the effect obtained with them.

Mr. W. FAIRBAIRN replied that the construction of the embankments for the storage reservoirs had been attended with great difficulties, and the case was very different from that of the Loch Katrine Water Works, where the supply of water was already impounded by walls of solid rock consisting of the hardest mica slate, and it was only necessary to cut a passage for drawing off the water. At the Longdendale reservoirs on the contrary the ground on both sides of the valley had been disturbed by landslips, and was still subject to occasional movements by subsidence or settlement. The discharge pipes from the reservoirs had been laid in the solid ground beneath the embankments. In the case of the Rhodeswood reservoir no alteration had taken place in the pipes, and the water was still discharged by this means; but at the Torside reservoir, the largest of the three great reservoirs in the valley, the ground beneath the embankment had become stretched by the weight of the superincumbent material, and drew the pipes to some extent asunder at the socket joints, crushing them also slightly. This evil had been obviated by driving a tunnel through the solid hill at one end of the embankment and laying fresh discharge pipes within this tunnel. There were two pipes in the tunnel, one 48 inches diameter and the other 24 inches, the latter being a syphon pipe by which the last 15 feet depth of water could be drawn out of the reservoir: there had been no difficulty in working this pipe, nor in other cases where syphons had been applied. The use of a syphon for discharging water from reservoirs had first been adopted by Mr. Bateman more than twenty years previously at the Belmont reservoir of the Bolton Water Works, and that pipe had been in occasional use ever since. The whole supply of water for Glasgow from Loch Katrine had also been taken off for nearly a year through a syphon pipe of 24 inches diameter, which rose about 7 feet above the level of the lake in order to pass over the cofferdam of the entrance basin, during the construction of that work.

The PRESIDENT moved a vote of thanks to Mr. Bateman for his paper, which was passed.

The PRESIDENT proposed a vote of thanks, which was passed, to Mr. Charles P. Stewart and the Local Committee for the excellent arrangements they had made for the meeting of the Institution in Manchester; and also to the authorities of the Mechanics' Institution for their kindness in granting the use of the Lecture Theatre for the purpose of the meeting; and to the several Railway Companies for the special facilities they had so kindly afforded to the Members for attending the Meeting in Manchester and the Excursions in connection with the meeting.

The Meeting then terminated. In the afternoon the Members visited the Whitworth Ordnance Works and the various engineering establishments and other works which were opened to their inspection during the days of the meeting.

In the evening the Members and their friends dined together, in celebration of the meeting of the Institution in Manchester.

On Thursday, 2nd August, an Excursion was made by the Members from Manchester, to visit the Cotton Machinery Works and Machine Brick Works of Messrs. Platt at Oldham, and some of the Cotton Mills adjoining; and the Members were very handsomely entertained by Mr. John Platt, M.P., at his residence, Werneth Park. They returned in the afternoon by special free train, granted by the Lancashire & Yorkshire and Manchester Sheffield & Lincolnshire Railways, visiting Messrs. Beyer Peacock and Co.'s Locomotive Works at Gorton, and the Ashbury Co.'s Railway Carriage and Iron Works at Openshaw.

On Friday, 3rd August, an Excursion was made by the Members from Manchester by special train, on the invitation of the President, to his residence, Stancliffe Hall, Derbyshire, where they were most hospitably received and entertained by the President; visiting also Chatsworth and Haddon Hall.

PROCEEDINGS.

15 NOVEMBER, 1866.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 15th November, 1866; SAMPSON LLOYD, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the Rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

JOHN PENN, ...	London.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

CHARLES F. BEYER, . . .	Manchester.
WILLIAM CLAY, . . .	Liverpool.
EDWARD A. COWPER, . . .	London.
THOMAS HAWKSLEY, . . .	London.
ROBERT HAWTHORN, . . .	Newcastle-on-Tyne.
EDWARD HUMPHEYS, . .	London.
SAMPSON LLOYD, . . .	Wednesbury.
HENRY MAUDSLAY, . . .	London.
W. MONTGOMERIE NEILSON, .	Glasgow.
JOHN RAMSBOTTOM, . . .	Crewe.

COUNCIL.

(Five of the number to be elected.)

ALEXANDER ALLAN, . . .	Worcester.
CHARLES EDWARDS AMOS, .	London.
JOHN ANDERSON, . . .	Woolwich.
FREDERICK J. BRAMWELL, .	London.
ROBERT BROAD, ...	Tipton.
CHARLES COCHRANE, . .	Dudley.
THOMAS GREENWOOD, . . .	Leeds.
WILLIAM MENELAUS, . .	Merthyr Tydvil.
C. WILLIAM SIEMENS, . . .	London.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

SAMUEL BAKER, ...	Liverpool.
GEORGE BARKER, . . .	Stoke-upon-Trent.
JOHN ADDISON BIRKBECK, . .	Chesterfield.
WILLIAM CRAVEN, . . .	Manchester.
ALFRED C. DOWNEY, . . .	Middlesbrough.
JOHN ELCE, ...	Manchester.
JAMES FLETCHER, JUN., . .	Manchester.
PETER BOYESEN FLOOD, . .	Durham.
JOHN SIMPSON FRASER, . .	London.
ALBERT FRY, ...	Bristol.
WILLIAM JENNINGS HOYLE, . .	Manchester.
HERRMANN FREDERIC JAEGER, .	Manchester.
WILLIAM BLAKE LAMBERT, . .	Berwick-upon-Tweed.
JOSEPH LEIGH, . . .	Patricroft.
GEORGE LITTLE, ...	Oldham.
EDWARD LORD, . . .	Todmorden.
ANDREW MUIR, ...	Manchester.
WILLIAM OLIVER, . . .	Chesterfield.

George Peel, Jun., . . .	Manchester.
Thomas Edward Day Plum, .	Manchester.
Charles Talbot Porter, . .	Manchester.
John Price, ...	Sunderland.
William Putnam, . . .	Darlington.
James Ramsden, . . .	Ulverstone.
Edward Windsor Richards, .	Ebbw Vale.
Thomas Robson, . . .	Fence Houses.
Edward Fisher Smith, . .	Dudley.
William Smith, . . .	Glasgow.
Robert Watson, . . .	Bishop Auckland.
Emile Watteeu, . . .	Middlesborough.
William Wray, ...	Burton Stather.

ASSOCIATE.

John Crossley, ...	St. Helen's.

GRADUATES.

Robert Harry Humphrys, . .	London.
Frederick Ryland, . .	Westbromwich.

The following paper was then read:—

ON SELLERS' SELF-ADJUSTING INJECTOR, AND OTHER IMPROVEMENTS ON GIFFARD'S INJECTOR.

By Mr. JOHN ROBINSON, of Manchester.

In the experience of the working of Giffard's Injector for the supply of water to steam boilers, which has now come so extensively into use both in this country and abroad, various requirements have been found to arise; and for the purpose of meeting these, several improvements of the instrument have been introduced, one of the most remarkable of which is an arrangement invented by Mr. William Sellers of Philadelphia, the manufacturer of the injector in the United States, to obviate the necessity of adjusting by hand the quantity of water supplied to the injector, and thus render the instrument to that extent self-adjusting.

In the original Giffard's injector shown in Fig. 1, Plate 95, the quantity of water allowed to reach the combining cone B is adjusted by means of the external regulating hand-screw F, which by raising or depressing the steam cone A increases or diminishes the annular opening for water. In Sellers' self-adjusting injector this opening is adjusted by the application of a piston in a cylinder, actuated by the amount of pressure or of vacuum existing alternately in the overflow chamber, according as the supply of water is in excess or deficient.

The construction of the self-adjusting injector is shown in the vertical section, Fig. 4, Plate 96, with the working portion enlarged in Fig. 5. A is the steam cone, B the combining cone, C the receiving cone; and the admission of steam through the steam cone A is regulated as hitherto by the handle D of the steam spindle I. The combining cone B at its base is so made as to form a piston E, which separates the water chamber G from the overflow chamber O. The interval J forms the entrance to the

receiving cone C, and also to the overflow chamber O, as shown in the transverse section, Fig. 6. The boiler valve H prevents the water returning from the boiler; and K is a waste cock, which when open allows the water and steam to issue into the atmosphere.

The mode of working the instrument is as follows. The waste cock K being first opened, the supply of water admitted from the tank is allowed to flow out through the waste; and the steam being then turned on by the handle D, an immediate increase takes place in the volume of water escaping at the waste cock, showing that the jet has been established. The waste cock is then closed, and the water flows into the boiler through the valve H. In case there should be too much water admitted to the combining cone B, the superabundance will be driven into the overflow chamber below the piston E, and will raise the piston so as to diminish the annular space between the combining cone B and the steam cone A, and thus reduce the water supply until the quantity admitted is in exact proportion to the supply of steam. The relative positions of these cones will then remain the same until some change takes place in the pressure of the steam. Supposing the pressure of the steam in the boiler should increase, so that a larger quantity of steam is discharged through the steam cone, the increased velocity of the jet will carry along with it into the boiler some of the water which had previously escaped through the opening J into the overflow chamber, and will thus produce a partial vacuum under the piston; the pressure of the water will then cause the piston to recede from the steam cone and admit more water, until the proper proportion is again established. At the junction of the water branch G with the main body of the injector a small valve L is provided, Fig. 5, opening outwards; and the escape of steam from this valve gives warning that the injector has ceased working from want of water, similarly to the escape of steam from the overflow pipe M in the original injector, Fig. 1.

In many boilers, such as those having a small water and steam capacity compared with their heating surface, and where the demand for steam is very irregular, the variations in the steam pressure are considerable and frequent, and the amount of attention

required for regulating an ordinary injector becomes somewhat inconvenient; under such circumstances the ingenious and simple arrangement now described for rendering the injector self-adjusting will be found extremely useful. It is evident that this arrangement of injector does not permit any overflow to take place after the injector is once started. Also as no air can get admission to the receiving cone of the injector, in consequence of there being no open overflow pipe, the entering water jet is not impeded in its progress by the contact of air tending to enter with it. In injectors having an open overflow, air can gain access to the entering water jet, and the quantity of water passing into the boiler is consequently diminished.

An arrangement for rendering the self-adjusting injector also self-starting has been contrived at the writer's works, in order to obviate the necessity for opening and closing by hand the waste cock K, Fig. 4; for when this cock has to be opened and closed by hand by the attendant at each time of starting the injector, it increases the number of manipulations, and may therefore perhaps be considered as a slight objection to the instrument in that form. In the improved self-starting injector, shown in Fig. 7, Plate 97, and enlarged in Fig. 8, the spindle of the boiler valve H carries a smaller conical valve S, which when the injector is not at work is always kept open by the pressure of the boiler upon the valve H, as shown in Fig. 8. When therefore the steam is first turned on for starting the injector, the water is at first allowed by the valve S to escape through the waste pipe Q; but as soon as the jet is established, the valve H opens to the boiler, and at the same time closes the conical valve S, and stops the escape through the waste pipe, as shown in Fig. 7. This arrangement has the advantage not only of rendering unnecessary the opening and closing by hand of the waste cock, but also of showing very clearly when the injector ceases working; because when that happens the boiler valve H is closed by the back pressure from the boiler, thereby opening simultaneously the valve S and allowing the steam and water to escape through the waste pipe Q.

In Fig. 2, Plate 95, is shown the improved arrangement of the ordinary injector with hand adjustment, designed by the writer and Mr. Gresham, which has now come into extensive use in place of the original form of injector. In the original injector, shown in Fig. 1, the combining cone B and receiving cone C are stationary, and the admission of water is regulated by sliding longitudinally the steam cone A, which is carried upon the extremity of a hollow cylinder N, passing through a stuffing-box at the top of the instrument, and requiring also an internal ring of packing at P, in order to prevent the steam from blowing through into the water chamber. With high pressure steam, such as 120 lbs. having a temperature of 350° Fahr., this internal packing becomes injured by the constant exposure to the high temperature whilst working, and involves the trouble of frequent renewal; and in order to obviate this difficulty, the improved injector shown in Fig. 2 is constructed with the converse arrangement of the cones, the steam cone A being made a fixture in the instrument, while the combining cone B and receiving cone C are cast together in a single piece sliding longitudinally, and are moved by the internal rack and pinion R. By this means the necessity for any internal packing is avoided, as no internal steam-tight joint is required; and at the same time the stuffing-box at the top of the sliding cylinder N, Fig. 1, is also done away with. The sliding cones B and C, Fig. 2, require only to be turned originally to an easy fit in their external cylindrical guides, as it is not necessary for these joints to be absolutely water-tight. The only additional requirement involved in this arrangement is the stuffing-box for the spindle of the pinion R, which is packed externally and has only to be made water-tight, in contrast with the internal steam-tight packing P in the original injector, Fig. 1.

The progress that has been made in increasing the delivery of water by the improvements effected in the injector is shown in the accompanying table, which gives the deliveries obtained at different pressures of steam with the self-adjusting injector and the rack and pinion injector, in comparison with the theoretical delivery as originally calculated by M. Giffard:—

Pressure of Steam. Lbs. per square inch.	Delivery in gallons per hour.		
	Giffard's original calculation.	Rack and Pinion Injector. Fig. 2, Plate 95.	Self-Adjusting Injector. Fig. 4, Plate 96.
Lbs.	Gall.	Gall.	Gall.
10	246	420	480
20	348	590	655
30	427	665	780
40	493	745	865
50	551	780	900
60	604	936	1081

Temperature of supply water 85° Fahr.

From this table it will be seen that considerable progress has been made in developing the capabilities of the injector since it left the hands of the inventor. In the case of the rack and pinion injector, shown in Fig. 2, the increased delivery may be attributed partly to the better vacuum obtained in the water chamber by the adoption of the fixed steam nozzle without packing, and partly to the more perfect concentration of the steam current upon the water current, in consequence of the greater length to which the steam cone A is inserted into the combining cone B. In the case of the self-adjusting injector, shown in Fig. 4, the steam cone A is also fixed; and as the exact quantity of water which the steam is capable of taking up is always admitted to the instrument by its self-adjusting property, it is evident that the injector once having the steam adjusted for the maximum delivery continues to deliver the maximum quantity of water which the pressure of the steam at any moment renders possible. On the other hand, in the case of an injector requiring the water admission to be adjusted by hand, it is impossible for the injector to produce constantly the maximum effect of water delivery when there is a continual variation in the pressure of steam, because the water supply cannot in ordinary practice be constantly adjusted by hand to suit the varying pressure.

There appears to the writer to be a possible drawback to the application of these self-adjusting injectors in cases where a high temperature of supply water is to be used, and especially where that temperature varies, as in the case of a locomotive engine. This

drawback consists in the probability that under such circumstances the injector might be difficult to start, because there is no open overflow pipe for allowing the surplus water to escape, and therefore a greater quantity of water cannot be used to condense the steam jet than can be admitted into the boiler in a given time through the receiving cone of the injector. With the ordinary open overflow however a larger quantity of water than can obtain access to the boiler may be admitted to condense the steam current, the surplus escaping at the overflow; and thus a feed can be established, although overflow may at the same time take place.

A simple means has also been arranged by Mr. Sellers for raising the supply water by the action of the injector itself, where the supply is at some depth below the level at which it is convenient to fix the injector. The arrangement adopted for this purpose is shown in Fig. 8. A small hole is drilled up the centre of the steam adjusting spindle I, throughout the length that is within the steam cone A, and four small transverse holes at the top admit the steam to pass down through the interior of the spindle as soon as the conical valve T is slightly opened. The combining cone B is so arranged as not to close the water passage entirely when the piston E is at the extremity of its range, as shown in Fig. 8, but to leave still a small annular space for the admission of the water from the water chamber G. The effect therefore of slightly opening the valve T is to allow a small quantity of steam to issue from the hollow steam spindle at a high velocity, and pass out through the waste pipe Q, taking with it any air which may exist in the water chamber G; by this means a greater amount of vacuum is produced in the water chamber than would be created if the steam were allowed to pass at a lower velocity through the annular orifice of the steam cone A. The conical valve T, Fig. 8, which was suggested at the writer's works, is also found to be a better method of shutting off the steam than by stopping the steam cone A with the end of the spindle I, as in Fig. 5; and the application of the valve T, Fig. 8, reduces the starting process to one operation, because when the water from the tank and the steam from the boiler are turned on, it is only necessary

to turn up the steam spindle by the handle D, Fig. 7, in order to start the injector.

Endeavours have been made by Mr. Barclay of Kilmarnock and others to construct an ordinary Giffard's injector in such a manner that it will draw water from a considerable depth; and this has been successfully accomplished to the extent of lifting the water from a depth of 15 or 18 feet below the water chamber of the injector, the temperature of the supply water being 60° Fahr. The construction of injector employed for this purpose is shown in Fig. 10, Plate 98; and the success is attributable to the care taken to obtain a better vacuum in the water chamber G by means of double stuffing-boxes U and V. One of these U prevents the escape of steam into the air, and the other V prevents the entrance of air into the water chamber G. Considerable importance is also attached to the advantage of a shielded steam cone A, shown to a larger scale in Fig. 11, the extremity of the cone being surrounded by an external casing, leaving an air space between of ¼ inch width closed at the bottom, which serves as a non-conductor to prevent the steam from being cooled and cause it to preserve its full heat to the very extremity of the steam nozzle. The steam adjusting spindle I is also made to project through the steam cone A into the combining cone B in the same way as in the original injector, Fig. 1, so as to secure not only an annular steam jet but also an annular combined jet; and the spindle is steadied near the extremity by the guide X, Fig. 11, to keep it truly central with the jet.

Another arrangement of injector for the same object is shown in Fig. 12, where the sliding steam nozzle has only a single stuffing-box W, which prevents the ingress of air to the water chamber; and the steam entrance is fixed upon the sliding steam nozzle, and moves with it, so as to preclude the necessity for a second stuffing-box to prevent leakage of steam. This construction requires however a flexible steam pipe, in order to allow for the motion of the sliding steam nozzle. When the injector is used for lifting water from a lower level, the steam cone A is first turned down by the regulating screw F to its extreme lowest position, as shown by the dotted lines, leaving a small annular passage for water between the steam cone

and the combining cone. The steam spindle I is then turned once round, which gives sufficient opening for the amount of steam required to exhaust the water chamber G. As soon as the water is seen to issue from the overflow pipe M, the handle F is turned so as to raise the steam cone A to a position suited to the pressure in the boiler, and the steam spindle I is drawn back until the overflow ceases.

It is evident that in these two arrangements of injector, as shown in Figs. 10 and 12, no leakage of either air or steam into the water chamber G can take place, to impair the vacuum capable of being produced by the jet of steam issuing through the combining cone.

The CHAIRMAN thought the self-adjusting injector described in the paper just read was a remarkably elegant and ingenious application of science to engineering practice; and he enquired how long it had been in use, and whether the new improvement could be adapted to injectors already existing on the previous plan.

Mr. ROBINSON replied that the self-adjusting arrangement had been devised with special reference to locomotive engines, to meet the constant variations in their steam pressure during ordinary work; and a great number of the improved injectors were already in use on locomotives in the United States, and it was now being endeavoured to render them suitable as far as possible to the requirements of locomotives in England. One obstacle at present to the adoption of the self-adjusting injector was that, as the overflow was entirely closed in, it made no noise when at work; and the enginemen did not like a quiet injector, having been accustomed to the old injector with the open overflow pipe, which they preferred on account of its making a noise in working, so that they could tell by the sound when it was at work. It would not be practicable to alter the previous injectors to the self-adjusting arrangement, as the extent of alteration required would amount to nearly as much as a new instrument.

Mr. C. W. SIEMENS remarked that, from the table given in the paper of the delivery of water obtained with the injector, it appeared that with a steam pressure of 10 lbs. the actual delivery obtained with the two forms of injector named was 420 and 480 gallons per hour respectively, while the calculated delivery was put down at only 246 gallons; and he enquired what was the explanation of this difference, and how it was that the delivery of the self-adjusting injector could be more than was given by calculation.

Mr. ROBINSON explained that the quantities put down in the column of theoretical delivery were those obtained from M. Giffard's original calculation of the delivery, and the calculation had been found to be incorrect, having been exceeded even by the early injectors, though only to a comparatively small extent at first. By subsequent improvements however in the proportions of the instruments, the maximum delivery had been still further increased, and this increase had been much more considerable in England than in France. Another point on which a mistaken idea had at first been entertained was the area of the steam cone, which had been made smaller in proportion for higher pressures of steam; whereas in reality a larger area was requisite with a higher pressure, in order to obtain a larger quantity of steam and so increase the velocity of the jet, and thus overcome the increased resistance of the boiler; and the greater degree of success attained in England with the injector, particularly at higher pressures, was to be attributed mainly to the adoption of a larger proportionate area for the steam cone.

Mr. F. J. BRAMWELL remarked that the quantities given in the table as Giffard's original calculation appeared to increase in the proportion of the square root of the increase in pressure, the delivery being put down at 246 gallons with a pressure of 10 lbs., while with four times that pressure or 40 lbs. the delivery was twice as great or 493 gallons. But by the two columns of actual delivery given in the table it appeared that the ratio of increase was somewhat less in practice, and therefore the proportionate difference between the calculated quantity as given in the table and the actual delivery obtained in practice would gradually diminish as the pressure increased.

The CHAIRMAN enquired what had been found to be the practical results of the improved injector as to its efficiency in working on locomotive engines.

Mr. ROBINSON said the self-adjusting arrangement was found a great improvement, by obviating the necessity for readjusting the admission of water to the instrument whenever any fluctuation occurred in the steam pressure; this adjustment had to be done by hand in the former injectors, and the engineman could not always readily attend to it just at the time when it was required. Another objection to the previous injectors was the constant dropping of water from the overflow pipe whenever the steam pressure fell, which was a great nuisance: this was entirely obviated in the self-adjusting injector, not merely by the fact of its being self-adjusting according to the varying pressure of the steam, but also by the whole instrument being entirely closed in, so that no escape of water at the overflow was possible after the starting cock had been closed at starting the injector to work.

Mr. C. W. SIEMENS asked whether in the self-adjusting injector the piston in the overflow chamber was always ready to act, or whether it was liable to stick; the self-regulating property of the instrument appeared to require considerable delicacy of action in the piston, especially in a small injector having a piston of small area. He enquired also, in regard to the self-starting injector shown in Fig. 7, in which the waste pipe was closed at starting by the opening of the boiler valve instead of by hand, whether it ever happened that the area of opening of the waste pipe was sufficient to discharge the whole jet of the injector, so that the boiler valve would not be opened by the jet at all; and he asked what proportion was adopted for the relative size of the waste aperture in order to prevent such an occurrence.

Mr. ROBINSON replied that it had been found in practice that the area of the waste aperture must not be more than $1\frac{1}{2}$ times the area of the receiving cone, otherwise the jet of water might possibly continue to escape from the instrument without producing sufficient pressure on the boiler valve for opening it into the boiler. With regard to the piston by which the injector was rendered self-

adjusting, it had certainly been feared at first that the piston would be liable to stick, especially with bad water. But it was found on the contrary that the real difficulty was to prevent the piston from moving so rapidly and so violently as to injure itself by striking against the top of the cylinder, when the injector did not start at once. When the injector was stopped by shutting off the steam, the back pressure from the boiler in closing the boiler valve drove the piston back with great rapidity to the top of the cylinder; and he had delayed bringing forwards the self-adjusting injector until the results of actual working had shown how the piston stood the amount of shock to which it was subjected. As far as could be ascertained from the use of the injector upon locomotives, it appeared that the piston was so sensitive that a variation of only 2 lbs. per square inch in the steam pressure was sufficient to move it; the piston was therefore always moving, and never stood still while the injector continued at work. The first trial made with the self-adjusting injector had been on an engine employed in shunting; and with the ordinary injectors previously used the water constantly jumped out of the overflow pipe from the shocks in shunting; but as there was no open escape in the self-adjusting injector, it was feared the piston might be too sensitive when the engine struck a train, and that the escape of water into the closed overflow chamber might cause so much motion of the piston as to stop the current of the jet. In practice however this had not been found to be the case, and he believed the self-adjusting injector worked more steadily when shunting than the previous injectors having the open overflow.

The CHAIRMAN enquired whether any packing was employed for keeping the piston water-tight.

Mr. ROBINSON replied that in the first self-adjusting injector the piston had been made with two grooves filled with light metal packing rings, as shown in Fig. 5; but this had been found unnecessary, and he believed it was better not to make the piston so tight in the cylinder, in order to ensure its moving freely with the variations in the steam pressure. The piston was therefore now made without any packing, as shown in Fig. 8, being merely turned

to an easy fit in the cylinder; and it was not necessary for it to be absolutely water-tight, just as in the pneumatic despatch tubes a small clearance was left all round the piston, without interfering with the efficiency in working.

Mr. H. Woods enquired whether by the employment of the self-adjusting arrangement there was any difficulty in working a large injector with only a small quantity of feed water. Supposing an injector were obtained large enough for feeding four boilers, he asked whether it could be conveniently employed for feeding one boiler only, whenever the other three might be out of work.

Mr. Robinson believed the improved injectors would allow of as great a range as 40 per cent. in the quantity of feed water, without the proper working being interfered with; and the self-adjusting arrangement would certainly have an advantage in cases where a varying quantity of feed was required, because the water supply adapted itself to every change made in the steam supply within the limits of range allowed by the instrument. The alterations made in the proportions of the new injectors had had the effect he believed of slightly reducing the minimum delivery of the injector as compared with its maximum, though not to any material extent beyond the original injectors. With all large injectors there still remained the same difficulty as previously in supplying only a small quantity of feed to a boiler; and the only way to manage was to feed for a certain length of time and then shut off, which was certainly a very inconvenient plan and only partially obviated by the self-adjusting arrangement. In travelling recently a considerable distance by railway he had been able to tell by the sound of the injector when it was at work or not, as it was one of the former sort with an open overflow; and he observed that the engineman started the injector whenever he stopped the train, and *vice versâ*, using the surplus steam to feed the boiler when not running, which appeared a very rational way of dealing with the difficulty of having an injector larger than was required for the work to be done.

Mr. W. Hackney enquired how the water was prevented from escaping at the small outlet valve placed on the water branch, as shown at L in Fig. 5, through which it was stated the steam would blow out whenever the injector stopped working for want of water.

Mr. ROBINSON explained that the small escape valve was held down to its seat by a spring put upon it, which was adjusted to the head of water supplied to the injector and had its outlet above the highest water level, so that it did not allow the water to escape in ordinary working, and was only opened by the pressure of the steam when there was not water enough for the working of the injector. This valve however he thought was not at all necessary, except perhaps on locomotive engines, where it served to call the driver's attention when the injector ceased working, in the same way as the escape of steam from the open overflow pipe of the previous injectors.

Mr. E. A. COWPER enquired whether injectors had yet been employed with complete success for feeding marine boilers. In an early attempt for that purpose some objection had been made to the injector on the score of its occasionally failing; and he believed the difficulty in that instance was partly owing to the circumstance of a number of boilers being ranged in a line, supplied by one main feed pipe, with the injector delivering in at one end of the pipe. When the ship was rolling therefore, the whole column of water in the long feed pipe acted like a ram, giving a very considerably increased pressure for the moment upon the injector, as there was no air vessel to relieve it; and thus the injector had to work against a varying pressure, running up much beyond the boiler pressure, so that its proper working was interfered with.

Mr. ROBINSON said that some time ago an injector had been applied in the "Fox" gunboat, which worked with complete success; the sea water for the injector was conveyed to it through a pipe of considerable length, and of course there was a considerable variation of pressure in the supply according to the inclination of the vessel in the water; but notwithstanding this varying pressure he had not heard of a single instance of failure or difficulty. The former prejudice against the use of the injector for marine boilers arose he believed from an accidental mistake in first applying the injector on the "Great Eastern," where an injector of the size intended for feeding only one boiler was set to feed six, and had of course proved incompetent; the supply of water was not merely insufficient, but it was not

introduced into the injector in the proper mode, and air was admitted with it, and the injector was consequently stopped. For marine purposes however he was at a loss to understand why the injector should not work as well as on locomotives, or indeed a great deal better, inasmuch as it was more efficient for low pressures than high. One difficulty indeed, which might possibly arise in feeding marine boilers, was deposit of saline matter from the sea water in the various passages of the injector, which might choke up the nozzles after a length of time. At present however no difficulty of that kind had been met with; and an injector applied in a steamer running from Liverpool to Quebec had continued feeding the boiler during the whole of the outward voyage without any stoppage at all.

The CHAIRMAN proposed a vote of thanks to Mr. Robinson for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A CURVILINEAR SHAPING MACHINE.

By Mr. FRANCIS W. WEBB, of Bolton.

This machine has been designed for the purpose of shaping the curved inner face of the rim of locomotive wheels between the spokes, so as to finish all portions of the rim to a true circle from the centre of the wheel, and leave the inner face of the rim parallel throughout to the turned outer face on which the tyre is bedded.

The machine is shown in Figs. 1 to 6, Plates 99 to 101. Fig. 1 is a plan of the machine; Fig. 2 a longitudinal section; and Figs. 5 and 6 are end elevations.

The wheel to be shaped, shown at A, Figs. 1 and 2, is mounted on a revolving table B on the bed of the machine; and a slow circular motion is given to the table by the ratchet-wheel and paul C on the worm shaft D, which works into the worm wheel on the table, as in an ordinary slotting machine. The table is moved forwards by the bed-screw E so as to bring the rim of the wheel under the vertical shaping tool F, which is carried in the extremity of the bent lever G. The centre of motion I of the lever coincides with the centre of the arc to which the inner face of the rim is required to be shaped; and this centre is either fixed, so as to shape all wheels to the same radius of curve, as shown in Figs. 2 and 3, or adjustable, as shown in Fig. 4, so as to allow of altering the radius of curve within the ordinary limits likely to be met with in practice. The tail end of the lever G is made with a long slot, in which works the crank pin J fixed in the vertical driving disc H, so that by the revolution of the disc the cutting tool is made to describe the required arc, as shown in Fig. 3; and the length of stroke of the tool is regulated by adjusting the crank pin J to the required radius

in the disc H. The disc being driven in the direction shown by the arrow, the tool has a quicker motion in the return stroke than in cutting.

On arriving at the junction of the rim with the spoke of the wheel, the rotation of the wheel is stopped by disconnecting the ratchet motion C; and by means of the worm-wheel and worm K Figs. 7 and 8, Plate 102, the tool F is turned slowly round in the lever G through a quarter circle, thereby rounding out the corner where the spoke joins the rim, as shown in Figs. 9 and 10. The tool is rotated either by a ratchet and paul on the worm shaft K, or by hand, the latter plan being found preferable in practice both for convenience and simplicity. The breadth of the toolholder is made exactly equal to the diameter of the circle to which the corner is to be rounded out; so that when the side of the toolholder comes up against the spoke of the wheel, as shown in Fig. 9, the tool is in the proper position for the feed motion C to be thrown out of gear, and the turning movement to be given to the tool by the worm wheel K.

As the radius of the curve at the corners of the spokes and rim is very small, the arm of the toolholder has to be kept out of the centre line of its shank. In the wheels for which the first machines were made, the radius of this curve was $\frac{3}{4}$ inch; and the front face of the toolholder was therefore made coincident with the centre line of the shank, and $1\frac{1}{2}$ inch wide, as shown in Figs. 7 and 8. With this arrangement the workman has no difficulty in fixing the tool with the proper amount of projection in the holder; for by winding the table round till the side of the toolholder touches the side of one of the spokes, as shown by the dotted lines in Fig. 9, and then turning the holder through a quarter circle, and fixing the tool so that its cutting edge just touches the side of the spoke, as shown dotted in Fig. 10, the tool is sure to be in the right position for shaping the rim of the wheel to the exact arc required, the whole adjustment being done with the greatest readiness.

The object of the writer in designing this machine was to bring the wheels of engines and tenders to a more correct balance, more

especially the carrying wheels, without at the same time increasing the cost of production; and the working of three of these machines at the Crewe Locomotive Works during the past twelve months has shown that a considerable saving is effected both in time and wages by this method of finishing a wrought-iron wheel forging, over the old plan of chipping and filing. A considerable saving is also effected in the smith's shop, as there is no necessity for planishing up the rims of the wheels; and by avoiding this planishing the rims can be left in the soft state, which the writer believes is preferable, rendering the wheel less liable to fail by fracture of the rim.

The writer's attention was more forcibly drawn to the subject of balancing the wheels, on occasion of examining a pair of leading wheels of an engine of the "Lady of the Lake" class on the London and North Western Railway, which had been reported as wearing the tyres very unequally. When the engine was examined, it was found that this unequal wear was not caused by any want of truth and squareness in the frame and axles; and the cause of the defect was then ascertained to be in the wheels themselves, which, though dressed on the inner face of the rim so as to look correct, were found on trial to be about 9 lbs. out of balance. After having been balanced, the same wheels were put to work again, and did not give any further trouble by unequal wear of the tyres.

Another case which occurred shortly afterwards was that of a first-class carriage, which when running at full speed had periodical oscillations fore and aft. On running the carriage experimentally to ascertain the cause, it was found that both pairs of wheels were out of balance, and one pair was of a different diameter to the other. Consequently when the two heavy sides got together and were in correspondence, violent oscillations occurred; and these gradually diminished as the heavy sides became more opposed to one another, by the smaller wheels over-running the larger ones and so bringing the two heavy sides to counteract one another; and the oscillations came on again as the smaller pair of wheels overtook the larger ones, bringing the heavy sides into conjunction again. The writer believes that if more attention were paid to the balancing of the carriage wheels, especially in the fast trains, there

would be fewer complaints of too quick running and bad roads; and at the same time a considerable saving in the wear and tear of tyres would be effected.

At Messrs. Sharp Stewart and Co.'s works in Manchester, where one of these machines is regularly at work, it is found that the cost in wages in the manufacture of wheels by the machine is about the same as by the old method of chipping and filing; but with two machines at work, as at the Crewe Works, the saving will be considerable, as one man can easily work both machines. The saving in files, which constitute one of the most considerable sources of expense in an engineering establishment, is also very great. It is found preferable for this slotting to be done dry, as the slight roughness thus left by the tool prevents the paint from being rubbed off; and with good steel there is no difficulty in completing the rim of a 5 feet or 6 feet wheel without once removing the tool for sharpening.

Mr. WEBB exhibited the working arm of one of the shaping machines, which had been lent for the meeting by Messrs. Sharp Stewart and Co., showing the action in shaping the rim of a wrought-iron wheel.

The CHAIRMAN remarked that the mode of shaping the inner face of a wheel rim by the machine described in the paper was certainly a novel idea in the manufacture of railway wheels, and well deserving attention, as a means of finishing them by machinery more correctly than could be done by hand. He enquired what length of time was occupied with the machine in going all round the rim of a locomotive wheel of 5 feet diameter.

Mr. WEBB replied that it would take about three hours to go round a wheel of that size, the machine requiring the attendance of one man; and the rim would then be finished to an exactly uniform thickness all round.

Mr. ROBINSON was convinced that the application of the machine described in the paper would rapidly extend, because it was well known that, as far as locomotive engine building was concerned, the use of tools was daily becoming more and more extended over every part of the work. In the case of all large forgings, the aim at the present time was to get them from the smith in large forged lumps, and then cut them down to shape in lathes and slotting machines, instead of employing smith's labour to work them down more closely in the first instance to the shape desired. In the forging of crank axles he remembered the time when as much as £7 was paid for smith's work in bringing the forging into shape ready for the lathe; but now the whole cost of shaping and finishing a crank axle was only from 40*s.* to 50*s.*, the smith never touching it at all after the forging of the original rough mass. This showed the great extent to which smith's work was now being superseded, and the expensive nature of that work was seen when it was considered that in addition to the smith's wages of 40*s.* per week each man required a couple of strikers to assist him, and a supply of coals for heating the work.

In the case of railway wheels an important portion of this cost of smith's work would be done away with by the application of the shaping machine now described. As the wheels were ordinarily constructed, the rim was welded up between each of the spokes, and in order to make it tolerably neat in appearance a considerable time was spent by the smith in planishing the inner curved surface of the rim, so as to bring it to the finished shape, while the outside of the rim was left rough to be afterwards turned in the lathe. By the application of the present machine however this additional labour was avoided, the inner face of the wheel rim being left rough by the smith, the same as the outside; and the smith's work was now confined to welding up the rim, leaving the whole of the finishing to be done by machinery. The result was of course a more mechanical job both in theory and in practice, avoiding those differences of thickness in the rim which were so detrimental to the steady running of the engines and the wear of the tyres. The application of the shaping machine to this purpose was therefore

unquestionably an important step in the right direction; and he thought the use of such a machine should not be confined to getting up the surface of railway wheels, as there were many other forms of iron work to which this curvilinear shaping movement might be advantageously applied.

Mr. WEBB mentioned that it had been suggested to make the inner surface of the rim flat instead of convex, so as to allow of shaping the wheel under an ordinary rectilinear slotting machine, without the necessity for a curvilinear motion of the tool; but the practical reason for making the inner face curved was that it would not be easy to ensure a sound weld with a flat surface, as the convex surface was required for enabling the hammers to strike well upon the inner face of the rim in the welding. The curvilinear movement in the shaping machine was therefore rendered necessary, in order to adhere to the curved shape of the face, and avoid cutting the iron to waste.

Mr. F. J. BRAMWELL remarked that, in the case of a railway wheel of 3 ft. 6 ins. diameter running at a speed of 50 miles an hour, each 1 lb. would have a centrifugal force of rather more than 90 lbs. or say $\frac{3}{4}$ cwt.; and therefore an amount of 9 lbs. out of balance, as mentioned in the paper, would cause a pressure on the bearing of about 7 cwts. in one direction, and then in 1-13th part of a second the same pressure in the opposite direction. It was only by taking into account the speed of revolution that the very serious effects could be appreciated of even so slight an error in balance.

Mr. WEBB observed that the value of perfect accuracy in balance of wheels running at a high speed was illustrated by the working of the traversing cranes at the Crewe Locomotive Works, in which the driving pulleys ran at a speed of 5000 feet per minute at the circumference, and had never given the slightest trouble since the cranes were first started in 1861, the pulleys having been each balanced very accurately in the first instance by trying them with the bearings on straight edges. In many cranes however, and other machinery employed in engineering workshops, there was no doubt that the wheels were not balanced as they ought to be; and much

trouble was consequently caused in keeping the whole in working order.

Mr. E. A. Cowper could confirm what had been said as to the importance of accurate balancing in machinery revolving at a high speed; for he remembered the case of a fan having arms of only a few pounds weight, where it was found that a strain of $2\frac{1}{2}$ tons was produced upon each arm in running at a high speed; and it was very surprising how much a small error in balancing would affect the revolution at high speeds. The employment of the machine now described for shaping the inside of the rim in railway wheels would certainly prove successful in establishing a perfect balance so far as the rim was concerned; and there remained only the spokes, in which any error of balance could exist, and he enquired whether any attempt had been made to finish the spokes by machinery in a similar manner. He had seen a machine employed for finishing the inner ends of the spokes at the boss, by slotting out the spaces between them with a round-nosed tool; but he did not know whether the body of the spokes was gauged with any degree of accuracy, though it was probable that the wheel was reasonably true in balance when the spokes had been forged in dies under the steam hammer. He concurred entirely in what had been said as to the importance of employing machinery instead of smith's labour for all work that could be done by machines; and in the case of roof work constructed of T iron he had introduced the plan of cutting off the iron by circular saws, so as to leave the ends true and thus save putting them into the fire at all, the castings for the joints being made to suit them; and by this plan a saving was effected of about 1*s.* 6*d.* per joint.

Mr. Webb said he had not yet attempted shaping the spokes of the wheels by machinery; and in forging the spokes under the steam hammer the practice at Crewe was to place a stop of the proper thickness upon the anvil, to limit the stroke of the hammer, so as to finish all the spokes exactly to the correct gauge both in width and in thickness. He was now introducing a modification of the machine described in the paper for the purpose of finishing the spokes at the neck, where they joined the rim, by means of a rose

cutter carried in a rest bolted upon the rim of the wheel; this revolving cutter would then finish the heads of the spokes completely, and there would be no occasion to use the file at all.

Mr. ROBINSON considered that spokes forged in a die would not be found to require any subsequent dressing, but would be practically all uniform in size and therefore in correct balance, with as much truth as if they had been cast in a mould.

The CHAIRMAN moved a vote of thanks to Mr. Webb for his paper, which was passed.

The following paper was then read:—

ON AN IMPROVED TOOL AND HOLDER FOR TURNING AND PLANING.

By Mr. W. FORD SMITH, of Manchester.

The important part which Cutting Tools perform in all engineering and machine-making establishments, and the large numbers of them that are constantly used, render it of considerable importance that the most efficient and economical form should be adopted. The idea of making the cutting portion of the tool in a separate piece, fixed in a stem or holder, instead of both forming one piece as usual, has been previously carried out to a limited extent and with partial success; but practical difficulties seem to have prevented the general adoption of the plan.

Round steel cutters, held in lathe slide-rests specially arranged for the purpose, have been to some extent successfully employed for turning rollers of small diameter for cotton machinery, and for this purpose they answer admirably; but these cannot be used for turning large diameters nor for facing large flat surfaces, and consequently are not generally applicable for all classes of turning, nor can this plan be employed in planing or shaping machines. In this mode of turning small rollers, special slide-rests are used, which are made to project under the rollers, having a small hole bored vertically in the top of the rest to receive a round piece of steel, ground to an angle at one end, which answers as the cutting tool. Where the rest reaches nearly to the height of the lathe centres, so that the steel cutter is not required to project a great height out of the rest, this arrangement answers satisfactorily for turning rollers of small diameter; but if rests were made on this plan for turning large diameters, the steel cutters would have to project so far out of the rest that they would be too unsteady to be practically useful.

Triangular steel cutters have been tried also with partial success; but the form of toolholder required for this section of steel precludes the possibility of sliding close up to a collar, for before the cutter itself can reach the collar the toolholder will come in contact with it or with any flange or flat surface, and will keep the cutting point from sliding up into the corner. Moreover this is practically a very expensive arrangement, as each triangular cutter requires to be nicely shaped and fitted into its holder; and if used for taking heavy cuts it is found difficult to prevent the cutter from being forced back into the holder: on these accounts the utility of triangular cutters is very limited.

The ordinary form of diamond-pointed tool, forged solid in one piece out of square bar steel, as shown in Fig. 1, Plate 103, is open to several objections. It is expensive to forge, particularly if made of the hooked form shown in the drawing. It requires to be ground both on the top and on the two sides; and the extent of these three surfaces renders the grinding expensive and complicated, especially if each surface is ground always to the correct angle. As the top surface becomes ground away, packing of different thicknesses is required to be placed under the stem of the tool, in order to raise the cutting part to the height of the lathe centres; and this causes waste of time. Also the tool will not turn both cylindrical and flat surfaces without its position in the slide-rest being altered. When the diamond-pointed tool is fed with a coarse traverse over the work, the surface produced is a series of ridges and furrows, as shown full size in Fig. 18, Plate 106; and the ridges require a considerable amount of hand labour to remove them, before a finished polished or scraped surface can be obtained.

In the improved Toolholder forming the subject of the present paper the cutting tool is separate from the holder, and is formed of a short piece of solid round steel, ground to the proper angle and fixed at the proper inclination in the toolholder, which is made of such a shape as to be applicable to all the principal descriptions of work. The toolholder is shown one quarter full size in Figs. 4 and 5, Plate 103; Fig. 4 represents one of the larger sizes,

and Fig. 5 a small size. Six different sizes are made, to suit the different sizes and classes of work, and for machines varying from large to small sizes.

The cutters A A are of the very best quality of steel that can be procured, and are made from bars of round steel cut into lengths with a cold set; each length is long enough to form two cutters, and is slotted through the centre while cold at the proper angle, as shown in Fig. 6, by a machine arranged for the purpose. The ends of a number of the cutters are then heated in a small furnace, and hardened in cold water. The toolholders B B are made of a strong and tough quality of steel, and after being forged nearly to the required shape are stamped while red-hot by a steam hammer in dies of the proper form. The upper and lower sides of the shank are planed parallel, to ensure its always bedding fairly and firmly in the toolboxes of the machines in which it is to be used; and the holder is then drilled for receiving the cutter, the hole being bored always at one standard angle, so as to give the correct angle of clearance to the cutter in every case, by means of a permanent inclined saddle upon the boring table, in which the holder is fixed.

The cutter is held in the toolholder by a steel set-screw C, shown half full size in Fig. 10, Plate 105, the end of which is recessed in the centre; and the portion of the cutter that it bears against is not hardened, so that the cutter is indented by the set-screw. The bite obtained by this means, together with the friction of the cutter in the toolholder, is sufficient to allow of a heavy cut being taken without forcing the cutter back in the holder. In order to prevent the cutter from becoming jammed in its hole in the toolholder by the slight burr raised upon it by the end of the set-screw, a clearance groove is slotted out down the side of the hole where the set-screw enters. The set-screw is placed square with the cutter, and at an angle of 30° from the face of the toolholder, so as to keep it well clear of the work. If an unusually heavy cut has to be taken, a toolholder is employed with a set-screw at the bottom, which is screwed up till it bears against the lower extremity of the cutter, as shown in Fig. 9, Plate 104, and in the specimen exhibited, which represents the exact position of the tool in actual working.

In the construction of these tools the angle that was found best for the clearance parts of the tools, Figs. 2 and 3, was adhered to as a standard in all cases, both for cutting cylindrical, taper, or flat surfaces in lathes, and for surfacing, down-cutting, or angling in planing machines; as any deviation from the best angle gives inferior results in cutting. The writer has found that an angle of 1 in 8 measured from the surface planed by the tool, as shown in Figs. 2 and 3, gives the best results. This inclination was accordingly adopted in the toolholder first made, for cutting surfaces at right angles to the shank of the toolholder, as shown in Fig. 3; and another holder was also made with the same angle of clearance on one of its sides, as shown in Fig. 2, instead of at the end, for cutting surfaces parallel to the side of the toolholder. Both of these however were superseded by the improved toolholder shown in Figs. 7 and 8, Plate 104, combining the two previous attempts in a single toolholder adapted to both purposes, having the angle of clearance both at the end and also at the side of the holder. The cutter is placed at the corner of the holder, so that the ground surface of the cutter is not square with either the side or the end of the holder, but midway between these two positions, at an angle of 45°, as shown in Fig. 7. It will be seen from the comparative diagram, Fig. 16, Plate 106, that the form of the new cutter closely corresponds with the most approved form of the cutting part in the best ordinary tools, the only difference being that the round cutter is made separate from the holder instead of being forged solid in one piece with it.

In Fig. 7, Plate 104, is shown at D a plan of the toolholder fixed on a slide-rest, with the tool in the act of turning the surface of a collar on a shaft, and thus cutting a flat surface. At E is shown the same holder still fixed in the same position on the slide-rest, but the tool is turning the cylindrical portion of the same shaft. The arrows show the direction of feed of the tool, at right angles to the shaft at D, and parallel with the shaft at E; but in both cases the most prominent round part of the cutter is seen to be fairly facing the metal, and the shavings escape at the same angle of 45° down the inclined ground surface of the cutter, so that the best effect is

produced in cutting. By this arrangement the tool is enabled to turn close up to collars and into corners, and to face the collars themselves and turn flat surfaces, or to do what is usually termed lathe surfacing, with the same toolholder and without moving its position in the slide-rest.

In turning cylindrical surfaces with the round cutting tools, it is of course requisite that the cutting point of the tool should be exactly on a level with the lathe centres, in order to produce a smooth turned surface. For this purpose a sheet-iron gauge of the simple form shown in Fig. 14, Plate 106, is supplied to each lathe, by means of which the tool is set up in the toolholder with complete accuracy to the exact height required; and the cutting edge being thus always level with the lathe centres, the turned cylindrical surface is finished as even and true as in planing a flat surface. As the tool is adjustable in the holder by the set-screw, it can be kept constantly at the proper height for cutting, without the necessity for inserting any packing under the toolholder in the toolbox of the lathe.

The toolholders are made in pairs, right-handed and left-handed, as shown in Figs. 12 and 13, Plate 105. Fig. 11 shows one fixed in the toolbox of a planing machine, planing the flat horizontal surface of a lathe bed; and the same toolholder is used for down-cutting vertical or angular surfaces. Fig. 13 shows it planing down the flat vertical surface of the inside of a lathe bed; and Fig. 12 shows a left-handed toolholder down-cutting the outer angle of a lathe bed.

For economy of work it is important that cutting tools should always be kept to the best forms and angles, and that the cutting portions should be of the best quality of steel, so that a maximum amount of cutting may be done at a minimum cost. To effect this the shortest time practicable should be spent in the cutting operation; and the work produced by the machine tools should be of the highest class, so as to require only a very small amount of hand labour to finish it after leaving the machines. Also such forms of cutting tools should be used that coarse traverses can be taken, so

that the tools can be fed quickly over the work and thick heavy shavings of metal removed, while at the same time a smooth even and correctly finished surface is produced. When the tools are ground to the proper shape, they give clean curled shavings; but if badly ground tools are used, the cuttings are forcibly torn off, and the surface of the metal presents a pitted torn appearance. In such cases even with fine traverses the whole power of the machine is frequently absorbed with indifferent results, the cuttings being crumbled up into small fragments when thus pulled or torn off, while the tool occupies much more than the proper length of time in traversing over the work, and a rough uneven surface is produced, which requires a great amount of hand labour to finish it. In this way much more engine power is expended in proportion to the work done than is requisite if a correctly formed tool is used. If the tool is too acute or keen, it springs slightly in cutting, and does not cut evenly, but makes successive digs into the metal and produces a jarring effect. If the best formed tools of the ordinary construction are placed in the hands of an inferior workman and he is allowed to grind them for himself on an ordinary stone, he is tempted to grind only the extreme cutting points, which alone are blunted by use, in order to save himself some hard work; but by this means the tools are gradually altered from the properly acute cutting edges to very obtuse angles, which will not cut the metal but only tear it off. The full lines in the drawing, Fig. 1, give an idea of the incorrect form to which the tools are frequently ground in this way. The outer dotted line shows the proper form, with both the clearance and the cutting angles correct for cutting cast metals.

All risk of inaccuracy in grinding the round cutters is obviated by the use of the principle of mechanical grinding introduced by Mr. Whitworth; and Figs. 19 to 22, Plate 107, show the grindstone designed for this purpose by the writer, the tools being held against the face of the stone in a slide-rest F adjusted at the correct inclination. The rest is traversed backwards and forwards by the handwheel G across the face of the stone during the grinding; and by the second handwheel H the tool is held up against the stone with the required pressure. By this means the grinding of the tools at the correct angle for cutting is always ensured.

The employment of these simple cutting tools of round steel, separate from the toolholder, is attended with several practical advantages of importance. The form of the cutters is the simplest possible, being merely plain round bar steel, which can be rolled to the proper size in the first instance, so that no costly forging is required, nor any shaping or fitting; and the lengths to form the cutters are cut off the bars in the cold state, and are never heated except for the purpose of hardening the points. As they do not require to be hammered into form, there is no risk of the quality of the steel being injured by burning, as is sometimes the case with ordinary tools when the steel has been overheated by the smith for rendering it more easy to work. The higher qualities of steel are not only harder and more difficult to work, but they will less stand overheating, and are more liable to crack under the hammer.

Another advantage is that the repairing of tools is altogether dispensed with, as the round steel cutters can be worn down from long to short lengths, without requiring anything more than grinding and occasional hardening. Moreover the grinding is reduced to the simplest possible operation, as the end of the cutters alone is ground, and the sides do not require touching. Hence the proper section of cutter is never altered, however much the tools are ground; and the amount of grinding necessary to restore the proper cutting edge is reduced to a minimum, whereby the expense also is diminished, and the grinding can be accomplished by cheap labour.

The cutters are all of one uniform pattern, whether large or small, being simply lengths of round steel; and one uniform cutting angle is adopted for all tools for cutting cast metals, and one angle for cutting wrought metals. Thus any number of tools of all sizes can be ground in the rest attached to the grindstone, by simply elevating the rest to the proper angle for the purpose required. The two angles that the writer has found to answer best for the cutting edges of the tools are shown in Fig. 15, Plate 106, which represents one of the angle gauges that is employed for testing the accuracy of the tools. These two standard angles are always adhered to for all the cutting tools; and the tools are tried by this gauge in grinding, the

slide-rest being set at the required inclination to the face of the grindstone.

At the writer's works in Manchester, where these tools are in general use, it is found that on an average fifteen of the round steel cutters are blunted in one day's work by each machine; and they take about $\frac{1}{4}$ hour for re-grinding them, or an average of one minute each. With the improved toolholder, in order to avoid the delay occasioned with the ordinary tools by the men having to grind their own tools when blunted, leaving their machines standing idle during the interval, a day's supply of tools ready ground is given out to each machine in the morning, and the blunted tools are collected for grinding ready for the following day. The small size and weight of the round steel cutters allow of carrying out this plan in practice with complete facility; but with the heavy tools of the ordinary kind it would be impracticable to keep on hand the stock of tools requisite for such an arrangement. The weight of the day's supply of fifteen cutters is not more than two-thirds the weight of a single ordinary tool; and the toolholder itself is about the weight of one ordinary tool for the same class of work. There is thus a great saving in carrying the tools backwards and forwards from the machines to the grindstone, as the light detached cutters alone are required to be carried, while the toolholder itself is not moved; and as the grinding is all done by one man, it is not necessary that all the men should have to learn how to grind their own tools, and complete uniformity in the grinding is ensured.

The maximum depth of cut which any of the round cutters will take is one half its diameter; and the largest size of the round cutters being $1\frac{1}{4}$ inch diameter, if a cut of more than $\frac{5}{8}$ inch depth is required, a cutter is employed made of an oval section of steel, $1\frac{1}{4}$ inch deep by $\frac{5}{8}$ inch thick. This oval cutter is capable of taking a cut of 1 inch vertical depth in planing a horizontal surface; and in order that the cutter may not be forced back in the holder by the severe pressure of so deep a cut, the holder is in this case made with a solid bottom behind the cutter; as the cutter becomes worn down a few blanks

from a punching machine are placed under its end to fill up the bottom of the socket in the holder.

The quality of the work produced by the round steel cutters is found to be much superior to that obtained with the ordinary diamond-pointed tools, under the same circumstances as regards depth of cut and amount of feed, the finished surface produced by the round cutters being remarkably smooth, even when taking a heavy cut. The superiority of the round cutters in this respect arises from the difference of their action, as illustrated in the diagrams, Figs. 17 and 18, Plate 106, which show full size one of the round cutters and an ordinary diamond-pointed tool, the dotted lines indicating an equal amount of feed in both cases. Since the smoothness of the finished surface increases in proportion as the thickness of the shaving diminishes, the diamond-pointed tool in taking a heavy cut leaves the surface as rough at the bottom of the cut as at the top, since the shaving removed is of uniform thickness through its entire depth, as shown by the shaded portion K in Fig. 18. But with the round cutter the shaving is only thick at the top, as shown by the shaded portion J in Fig. 17, and the thickness gradually tapers away to almost nothing at the botttom, where the shaving becomes nearly a tangent to the circular cutting edge of the tool. Consequently although the surface left by the round cutter is as rough at the top of the cut as with the ordinary tool, this is of no importance, as that part of the surface will be planed away at the next stroke; while at the bottom of the cut the finished surface is as smooth as if the whole depth of the cut had been no greater than necessary to give shavings as thin as at this part.

This difference in the quality of the work produced by the round cutter as compared with the ordinary diamond-pointed tool is shown in the specimen of work exhibited to the meeting. An ordinary diamond-pointed tool with a slightly rounded point was first started and allowed to plane a width of $\frac{5}{8}$ inch over the surface of the wrought-iron plate exhibited. One of the round cutters, $\frac{3}{8}$ inch diameter, was then started to plane where the first left off, and after planing about 1 inch width was stopped in the middle of a cut. The feed was exactly the same in both cases, and the tools cut dry,

without soap and water. It will be seen that the round cutter has left a very fair finish for a rough dry cut, which contrasts favourably with the finish left by the ordinary diamond-pointed tool; also the minute ridges left between the successive cuts of the round tool are hardly perceptible, being only about one fifth of the height of the ridges left by the ordinary tool, as shown in the diagrams, Figs. 17 and 18.

This experiment served also to determine approximately the amount of power required to drive the round cutters, which is found to be only about three fourths of that necessary to drive the ordinary tools for doing the same work. The ordinary diamond-pointed tool employed in the experiment was shaped to the most approved form for cutting wrought iron; and the depth of cut being 3-16ths inch with a feed of 24 per inch, it was found that a weight of 74 lbs. was required, pulling direct upon the driving strap, to enable the tool to take the cut. After planing the width of $\frac{5}{8}$ inch, the round cutter, $\frac{3}{8}$ inch diameter, was substituted, going on from where the other had left off, and working under precisely the same circumstances; and the weight required upon the strap was only 56 lbs., or about three fourths of that required with the ordinary tool.

With regard to the saving effected in current expenses by the use of the improved toolholders and round cutters, it has been found at the writer's works that one smith and striker, who had been almost wholly employed in repairing and making the ordinary solid forged tools, are now dispensed with; and instead of two grindstones being always fully occupied in grinding the tools, the whole grinding of the cutters is now done by a single stone, requiring only one man for the purpose, instead of the time of the machine men being taken for grinding their own tools. Assuming therefore that the time of three men only is saved in grinding and repairing, at wages of only £1 each per week, this alone represents a saving of £150 per year; and this saving is independent of the increased quantity of work produced with the improved toolholders, in consequence of the machines being kept constantly running; while there is also the saving in engine power, and in finishing the work as it comes from the machines.

Mr. W. F. SMITH exhibited a number of the improved tools and toolholders, with specimens of work planed and turned by them, showing the character of the work done; and also specimens showing the amount of re-sharpening required by the tools after work.

The CHAIRMAN thought the improved plan of tools described in the paper had important practical advantages, and he was sure its introduction would be a subject of much interest to engineers, if from its simplicity and economy these advantages were realised.

Mr. E. A. COWPER thought the new plan of tools would prove very useful in engineering workshops, and would be particularly valuable in saving the loss of time at present involved in the grinding up of the tools, as it was most frequently the case that the machine was standing idle during the time of grinding. He enquired what was the quantity of work done in a day by the new tools in comparison with that got through by the ordinary tools when ground in a reasonable manner.

Mr. W. F. SMITH replied that he was not able to state the exact difference in the quantity of work produced; but that there was a decided advantage in this respect on the part of the new plan was shown by the fact that at his own works, although some of the piece-work prices had been considerably lowered since the new tools were introduced, the men were now making more wages than they ever did before under the old plan, and they would not work with the ordinary tools now that they could get the new ones.

Mr. J. MURPHY considered the new plan of tools would be productive of a great amount of economy in all engineering shops; and in his own works he should himself be very glad to adopt the plan. In turning the hard tyres that were made at the present time for railway wheels, the turning tool was generally made of a bar of $1\frac{1}{2}$ inch steel, and he had found great difficulty in getting any steel hard enough to stand the heavy cut required, and such steel could only be obtained at a higher price. But when the tool had become worn down to a short length of 7 inches of steel it had to be put aside, as there was a difficulty in welding these short lengths of such a hard quality of steel. The round cutters on the other

hand, that were used in the new plan of tools, could be hardened to any extent, and when worn down to a short length it was only the cutter itself that had to be thrown aside and replaced, the toolholder remaining unaltered. The greatest practical difficulty however which he had experienced with the ordinary tools was to get the men to grind them to the correct angle, each man having his own idea as to the best cutting edge; and it was therefore a great advantage in the new plan of tools that the men would not grind their own tools, and that the construction ensured the whole of the tools being correctly ground to the proper angle.

Mr. J. B. FENBY enquired whether any difficulty had been found from the toolholder springing, and thereby causing the tool to dig into the work in turning and planing. In the case of turning, he suggested that this might be obviated by placing the cutting edge of the tool just below the level of the neutral axis of the stem of the toolholder, instead of above it, so that the tendency of the tool would be to clear itself if there were any springing of the holder; and similarly in reference to planing. He noticed also that in the arrangement shown for grinding the tools the grindstone was represented as turning from the tool, which was generally considered to produce a ragged edge on the tool very soon; but by making the grindstone revolve in the opposite direction towards the tool, a much smoother and firmer edge was produced, and he had found that tools ground in this way would last half as long again as if ground on a stone revolving from the tool.

Mr. W. F. SMITH replied that the digging in of the tool was simply a question of the angle of the tool and the position of the slide rest. If the cutting edge of the tool were made too acute, it was sure to dig into the work, provided the cut was heavy enough; but by taking care to keep the cutting edge of the tool exactly level with the centre line of the work in the lathe, and by having the tools all ground correctly to the proper angle, he had found there was no risk of any such occurrence. With respect to the direction of revolution of the grindstone for grinding the tools, it appeared to him to be quite immaterial whether the stone turned one way or the other. In grinding with the stone revolving from the tool, as

shown in the drawing, a mere thin film was found to be left on the edge of the tool after grinding, which was taken off by rubbing the tool on the stone by hand. The principal object in grinding the cutters in this way instead of the other was to make the stone available also for grinding tools by hand on an ordinary hand-rest placed on the opposite side of the stone to the slide-rest.

Mr. WEBB remarked that in taking heavy cuts in hard metal it was always found advisable to make use of a large tool for the purpose, in order to carry away the heat from the point of the tool; and in this respect therefore a small tool, such as the round cutter in the new tools, seemed undesirable for that class of work. Another objection to a small tool was that it had not stiffness enough for a very heavy cut.

Mr. W. F. SMITH explained that with the new tools it was not intended to take a deep cut with a small diameter of tool, and the depth of cut ought not to be more than about half the diameter of the tool, when the tool was made of round steel. For a deep cut an oval tool was employed, as shown by the specimen exhibited, which was suitable for a cut 7-8ths inch deep; and with this depth of cut the tool would take about ten cuts per inch of feed.

Mr. ROBINSON considered it was very important to put a stop to the great waste of steel which at present took place with the ordinary tools, both in originally forging them to the required shape and also subsequently in the large amount of grinding that was necessary for keeping them up to the proper form; and he was therefore much pleased to learn the very satisfactory manner in which the new plan of round cutters in permanent holders had already been worked out in practice, as described in the paper.

Mr. E. A. COWPER concurred in the great practical value of having all the tools in a shop made to the same cutting angle; and the form of gauge described in the paper for giving the correct angles of the cutting edges appeared very simple and convenient for the purpose. For the ordinary tools at present in use a simple gauge for the front of the tool had been designed by Mr. Nasmyth, as described by Holtzapffel, consisting of a vertical cone having its sides at an angle of 3° to the vertical, set upon a horizontal plane;

and the correct angle for the front of the tool was tested by placing the tool upon the flat surface and bringing it up against the cone. With the round cutters he thought that a still further improvement might be made for finishing the work, by using a tool having a small portion of its cutting edge straight, by making the cylindrical tool with a flat surface throughout on one side, so as to remove the slightest trace of ridges on the finished surface of the work; just as with the ordinary angular tools at present in use the workman in taking a finishing cut would grind off the extreme point of the tool, and so leave a straight part between the two inclined edges. The mode of grinding the tools, with the grindstone revolving from the tool, as shown in the drawing, would have the effect he thought of giving a ragged edge to the tool, and it appeared preferable therefore to run the stone in the opposite direction, as in grinding the edges of the ordinary cutting tools. The new plan of tools was certainly admirably worked out, and appeared well calculated not only for saving cost but also for improving the quality of the work done.

Mr. W. F. SMITH said that on the first introduction of the round cutters he had found the men flattening the cutting edge for the finishing cut, under the idea that this was necessary for preventing ridges on the work; but this was not allowed now, as any flattening of the cutting edge did away with the peculiar advantage of the round tool in accuracy of the cutting angle, the amount of flattening being altogether a matter of uncertainty, dependent on the judgment of each separate workman. Theoretically there was of course inevitably a slight ridge left between the successive cuts of a round tool traversing along the work; but in practice, when the rate of feed was properly proportioned to the diameter of the cutter, these ridges were so exceedingly minute as to be altogether inappreciable, and the result was a practically smooth surface, quite as smooth as that produced with the best of the ordinary tools.

The CHAIRMAN enquired whether the round cutters were found applicable to all descriptions of machine work.

Mr. W. F. SMITH replied that the round tools were found by experience to be equally applicable for all descriptions of straight

work, such as planing and turning, and partly also for slotting; but for drilling and boring machines they were of course not suitable. In special cases of turning out sharp corners where a square corner was particularly desired, it would of course be necessary after using a round tool to substitute one of the ordinary diamond-pointed or square tools to reach into the corner, as the round tool left all corners rounded out to a circle of its own diameter.

Mr. F. J. BRAMWELL thought the round tool had a decided advantage for turning collars on shafts, because it was then impossible for the workman to spoil the work by cutting out the corners square, as was too frequently done; but with the round tool he would be compelled to leave them all nicely rounded out.

The CHAIRMAN enquired what were the two angles in the standard gauge employed for giving the inclination of the round cutters.

Mr. W. F. SMITH replied that the angles of the gauge were 50° for wrought iron, and 60° for cast iron and brass, which were the angles that he had found the best for the different descriptions of metal.

The CHAIRMAN proposed a vote of thanks to Mr. Smith for his paper, which was passed.

The Meeting then terminated.

Fig. 1. *Vertical Section of Governor for Clocks, &c. Scale half full size.*

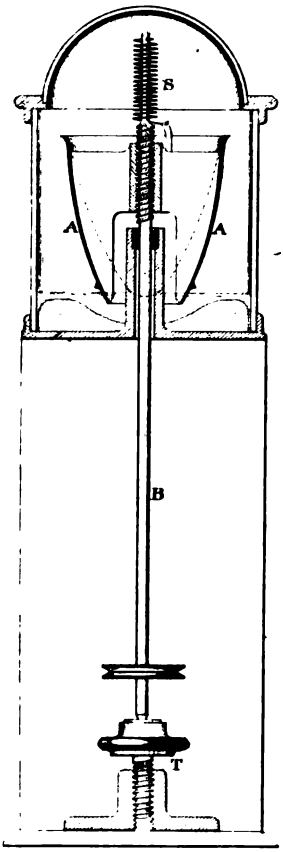


Fig. 2.

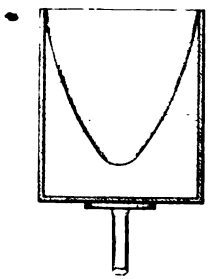
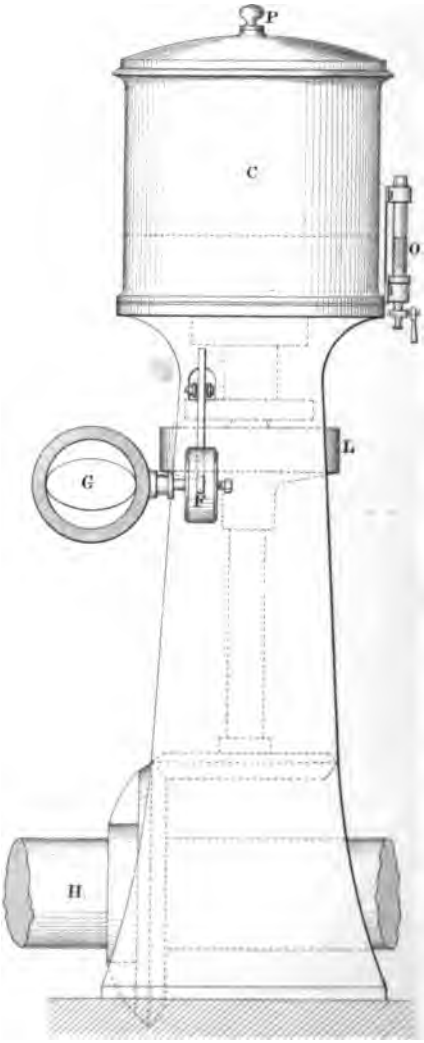


Fig. 3. *Side Elevation of Steam-Engine Governor.*

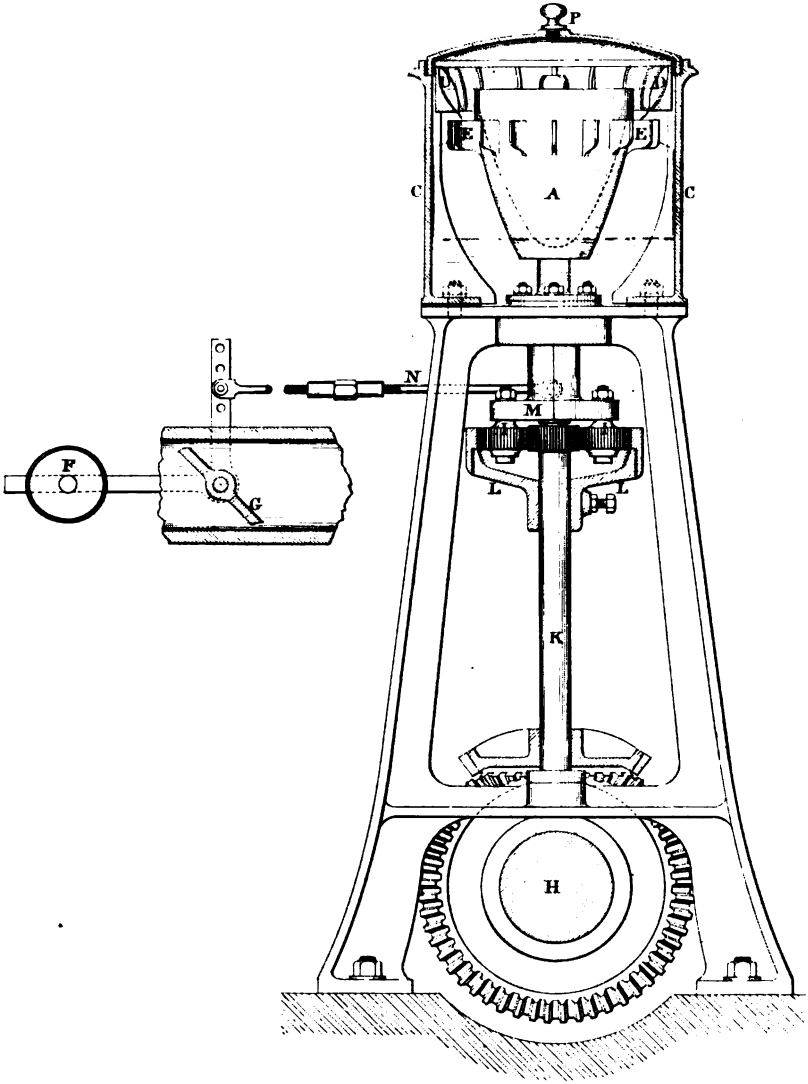


Scale 1/10 th

(Proceedings Inst. M.E. 1866. Page 19.)

CHRONOMETRIC GOVERNOR. *Plate 2.*

Fig. 4. *Vertical Section of Steam-Engine Governor.*

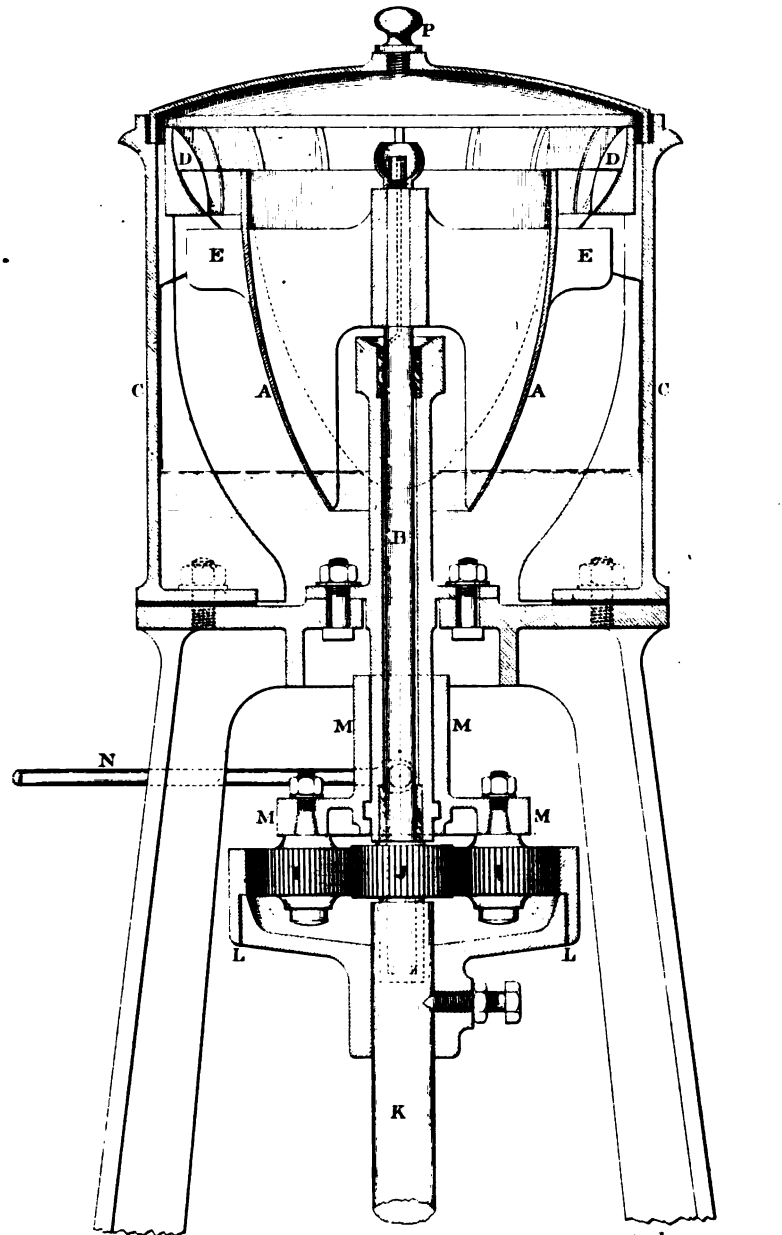


Scale 1/10th

0 10 20 30 Inches.

(Proceedings Inst. M.E. 1866. Page 19.)

Fig. 5. *Vertical Section of Steam-Engine Governor, enlarged.*



(Proceedings Inst. M.E. 1866. Page 19.) *Scale 1/5th*

Steam-Engine Governor.

Fig. 6. *Sectional Plan of Revolving Cup.*

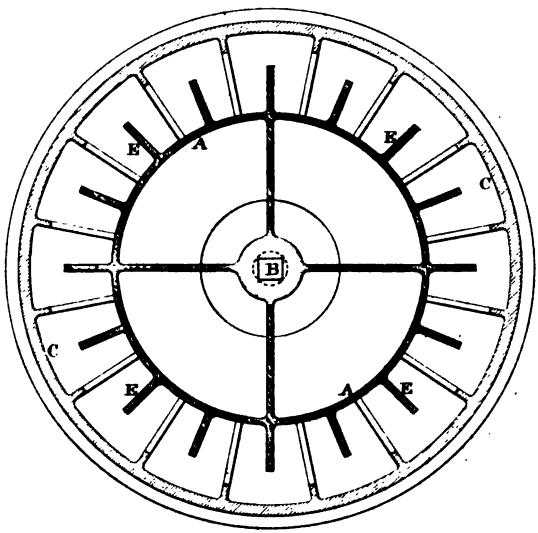
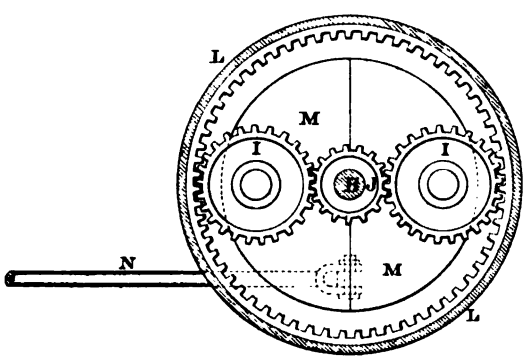


Fig. 7. *Inverted Plan of Differential Wheels.*



(Proceedings Inst. M.E. 1866. Page 19.) *Scale* $\frac{1}{3}$ *th*

0 5 10 15 Inches.

WROUGHT IRON TURNTABLE.

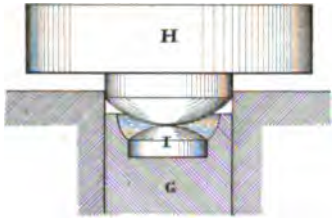
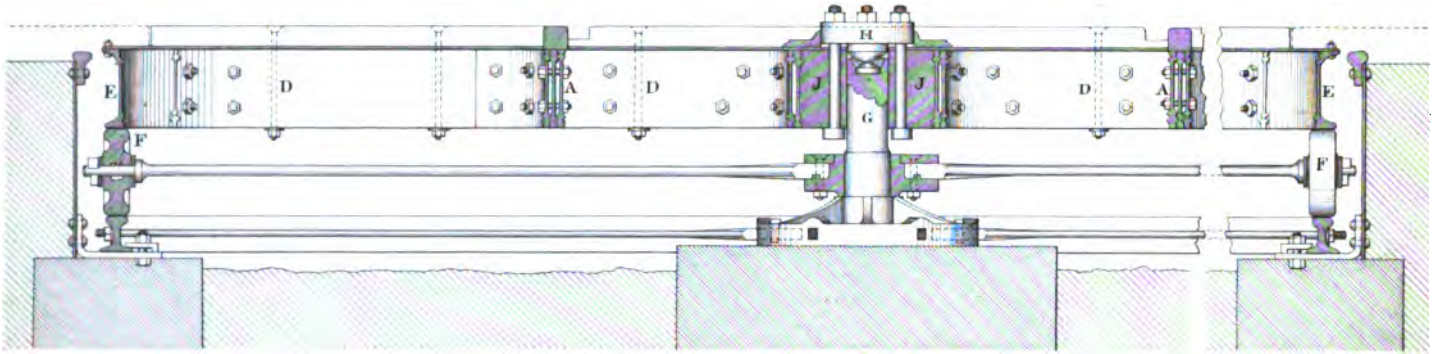


Fig. 2. *Cast Iron Centre Bearing. Scale 1/6th.*

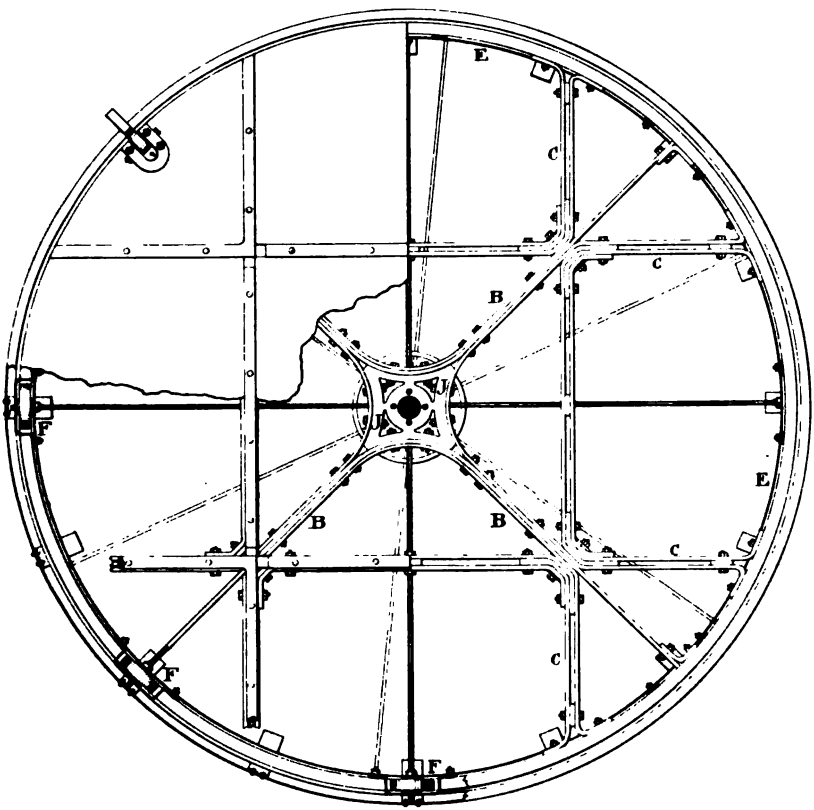
Fig. 1. *Vertical Section of 12 foot Turntable.*



(Proceedings Inst. M.E. 1866. Page 43.)

Scale 1/18th.

Fig. 3. *Plan of 12 foot Turntable.*

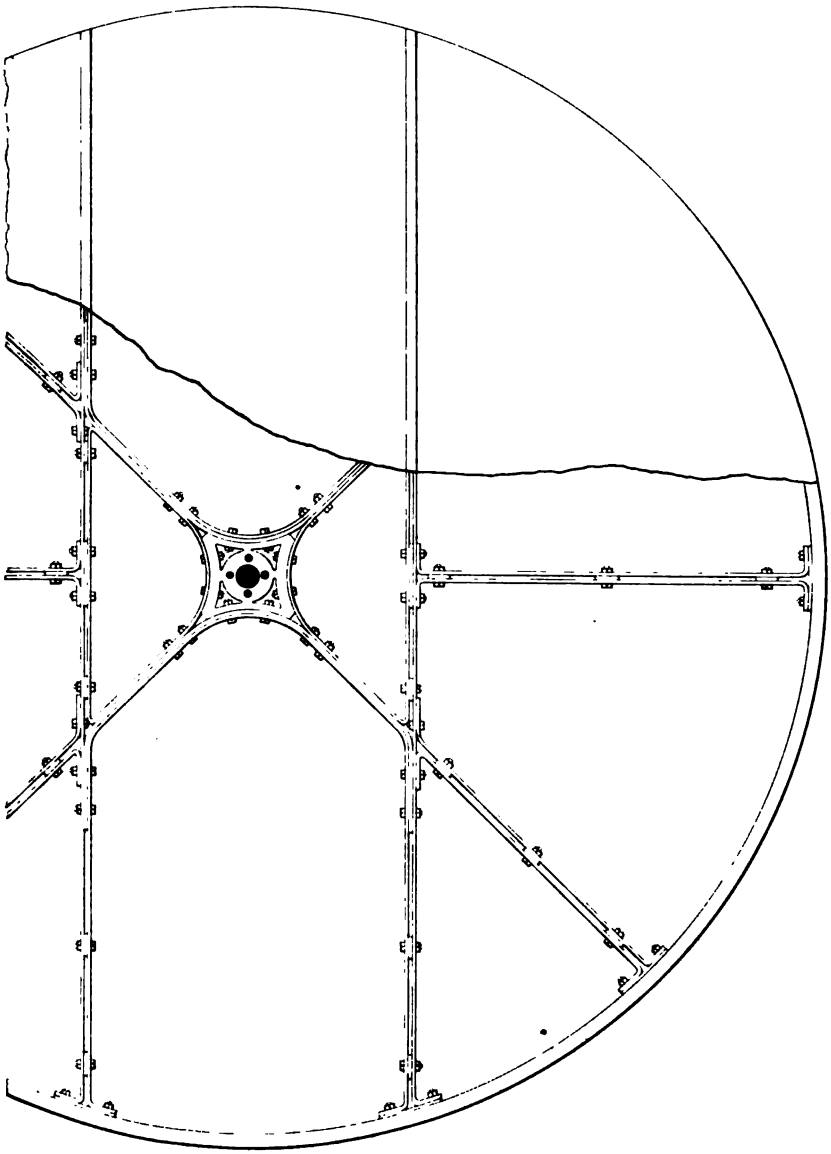


Scale 1/36 th

0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst M.E. 1866. Page 43.)

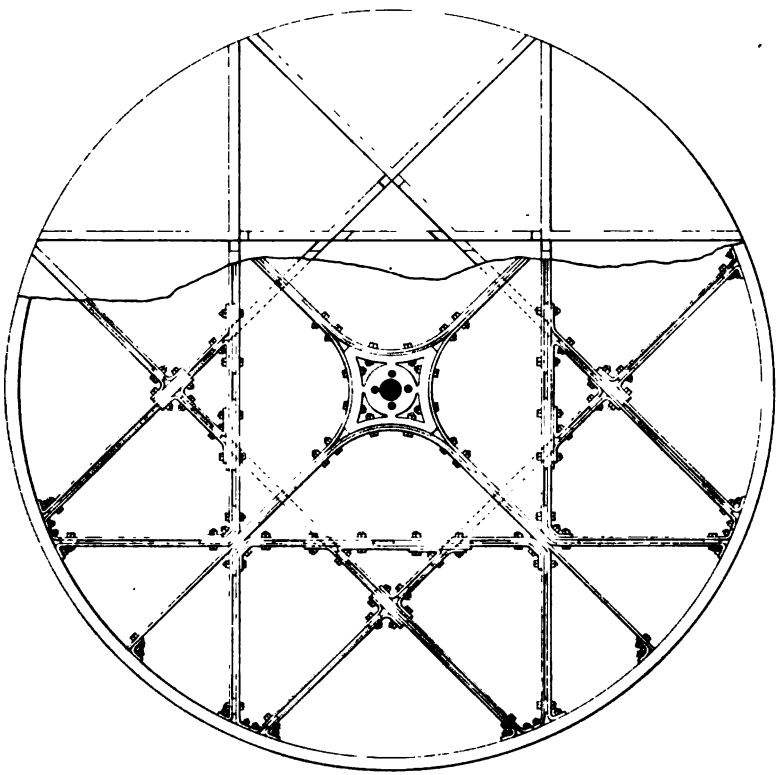
Fig. 4 *Plan of* 18 *foot Turntable.*



(Proceedings Inst. M.E. 1866. Page 43.) *Scale* 1/36th

0 1 2 3 4 5 6 7 8 9 10 Feet

Fig. 5. *Plan of Four-Line Turntable.*



Scale 1/36 th

0 1 2 3 4 5 6 7 8 9 10 Feet

(*Proceedings Inst. M.E. 1866. Page 43.*)

Fig. 6. *Vertical Section of Wrought Iron Centre.*

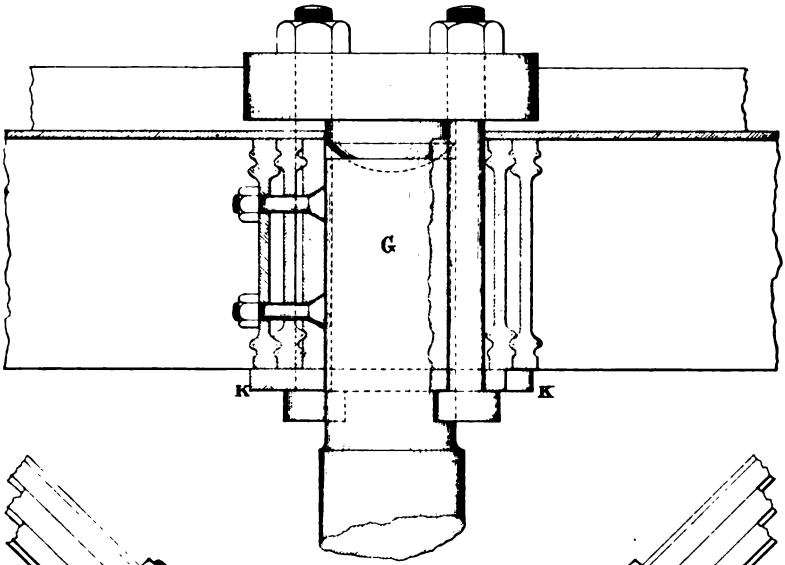
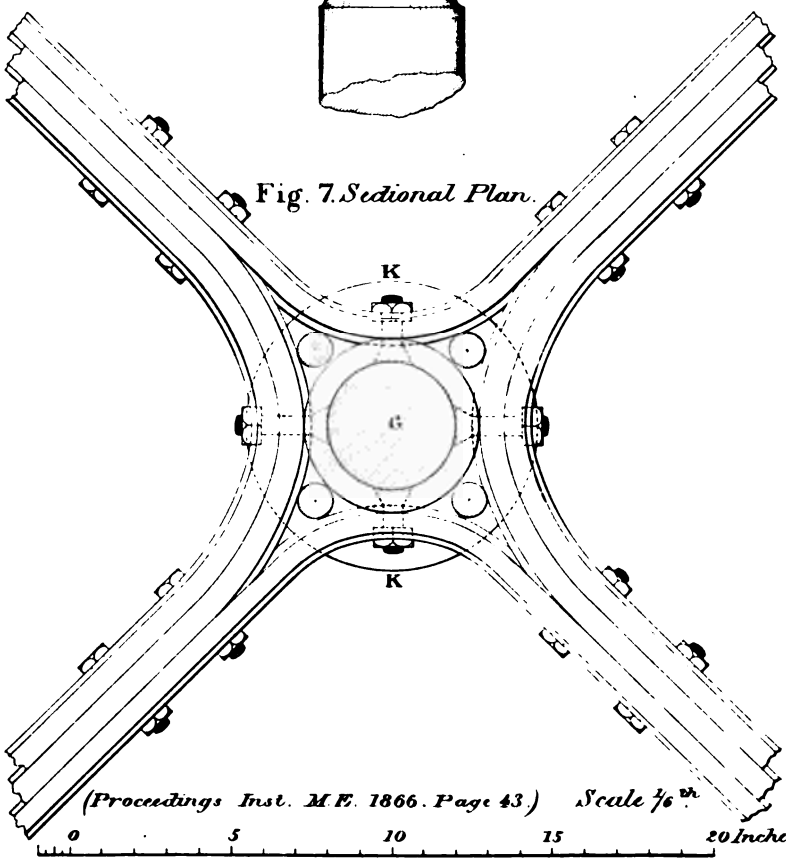


Fig. 7. *Sectional Plan.*



(Proceedings Inst. M.E. 1866. Page 43.) *Scale 1/6th*

0 5 10 15 20 Inches.

WROUGHT IRON TURNTABLE.

Plate 10.

Fig. 8 *Section of Single Bar of Turntable.*

Fig 9. *Section of Compound Girder of Turntable.*

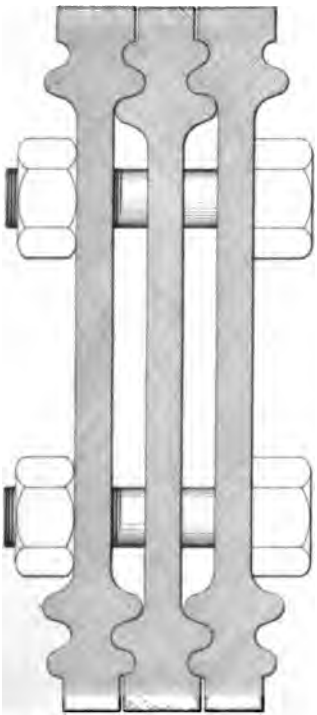


Fig 10. *Section of Rim of Turntable.*

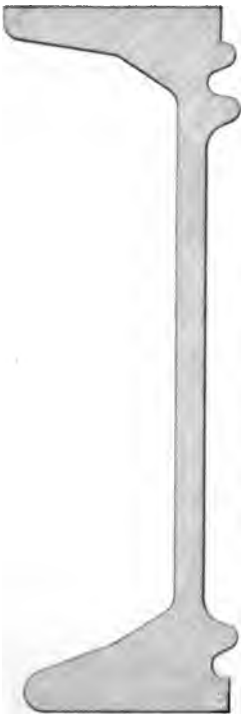
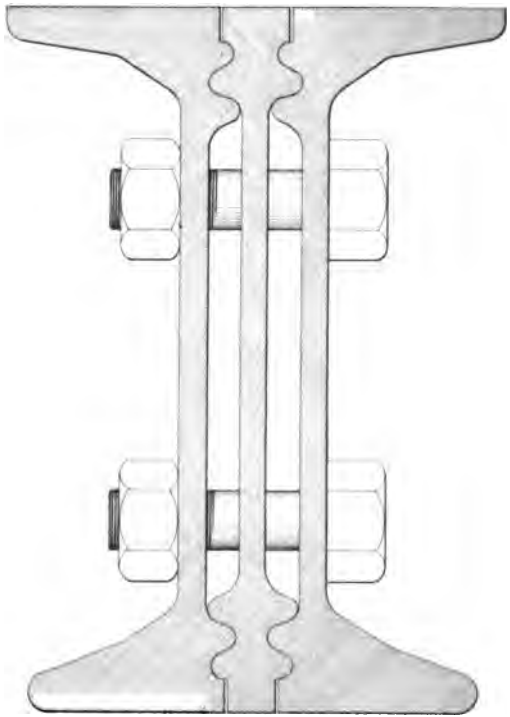


Fig 11. *Girder formed of two Rims with intermediate Single Bar.*



(Proceedings Inst. M.E. 1866. Page 43.)

Scale half full size.

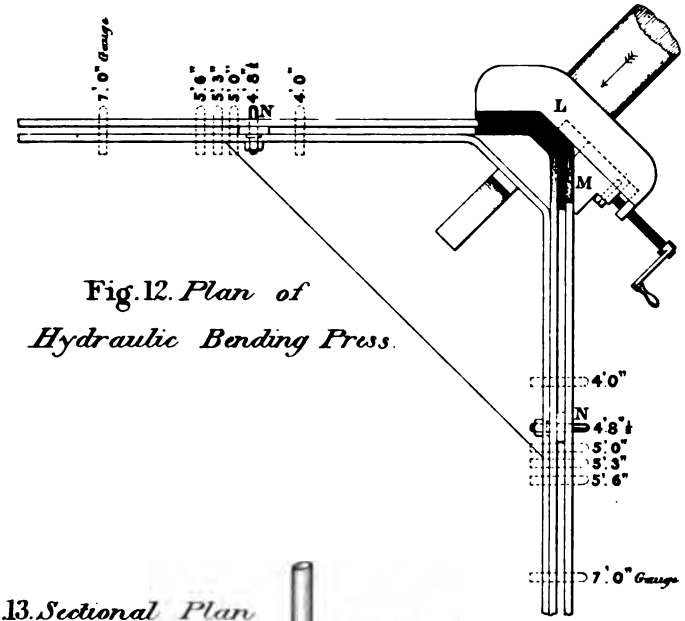
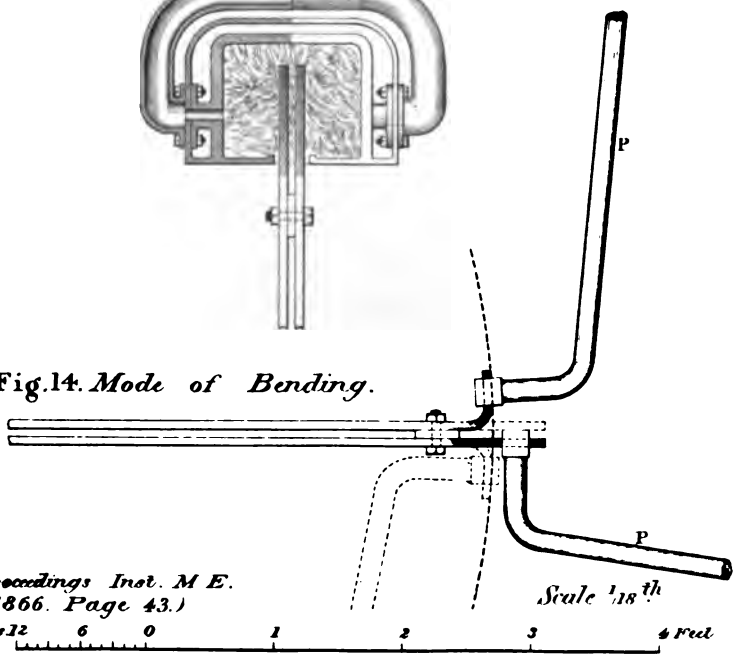


Fig. 12. *Plan of Hydraulic Bending Press.*

Fig. 13. *Sectional Plan of Portable Forge for Bending Ends of Bars.*

Fig. 14. *Mode of Bending.*



(*Proceedings Inst. M E. 1866. Page 43.*)

CORROSION OF LOCOMOTIVE BOILERS. *Plate 12.*

Diagrams showing Grooving caused by Corrosion in ordinary Boiler Barrels with Angle-Iron and Lap Joints.

Grooving at Angle-Iron Joints at Smokebox and Firebox ends.

Fig. 1. *Plan of Inside of Boiler Plate at Smokebox end.*

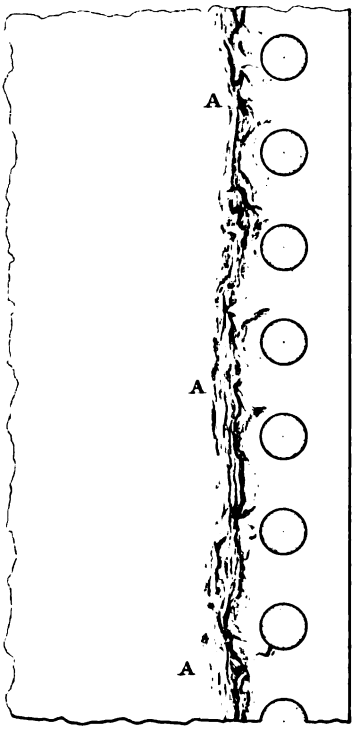
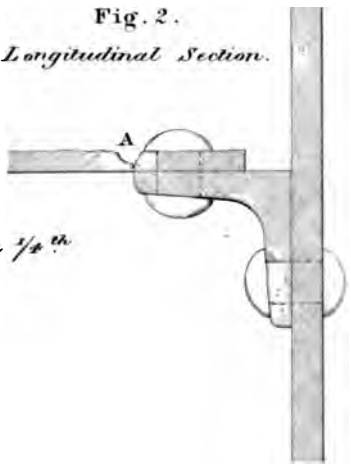


Fig. 2.

Longitudinal Section.

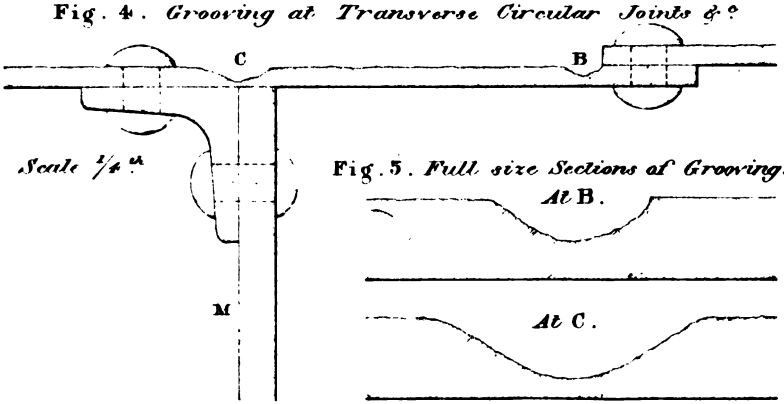


Scale 1/4th

Fig. 3.

Full size Section of Grooving at A.

Fig. 4. *Grooving at Transverse Circular Joints &c*



Scale 1/4th

Fig. 5. *Full size Sections of Grooving.*

At B.

At C.

(Proceedings Inst. M. E. 1866. Page 56.)

CORROSION OF LOCOMOTIVE BOILERS. *Plate 13.*

Diagrams shewing Grooving caused by Corrosion in ordinary Boiler Barrels with Lap Joints.

Fig. 6. *Grooving at Longitudinal Joints.*

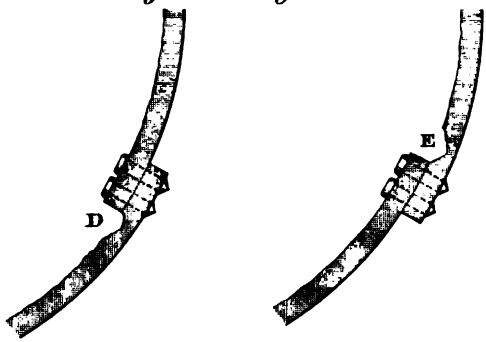
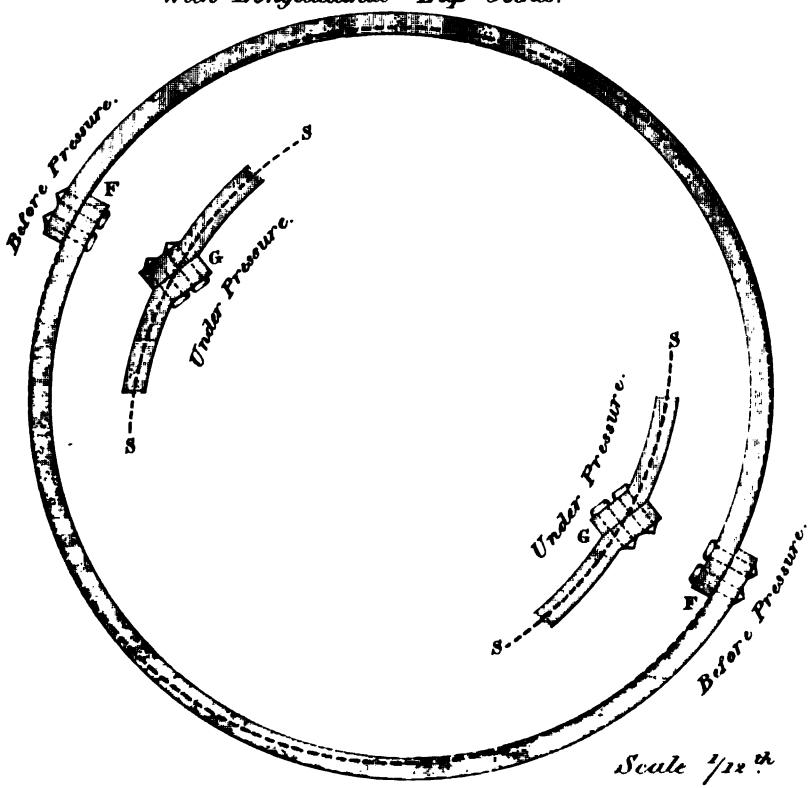


Fig. 7. *Transverse Section of Ordinary Boiler Barrel with Longitudinal Lap Joints.*



Scale 1/12th

Thickness of Plates magnified 3 times.

(*Proceedings Inst. M. E. 1866. Page 56.*)

CORROSION OF LOCOMOTIVE BOILERS.

Plate 14.

Diagrams shewing line of Longitudinal Strain in Boiler Barrel, before pressure and under pressure.

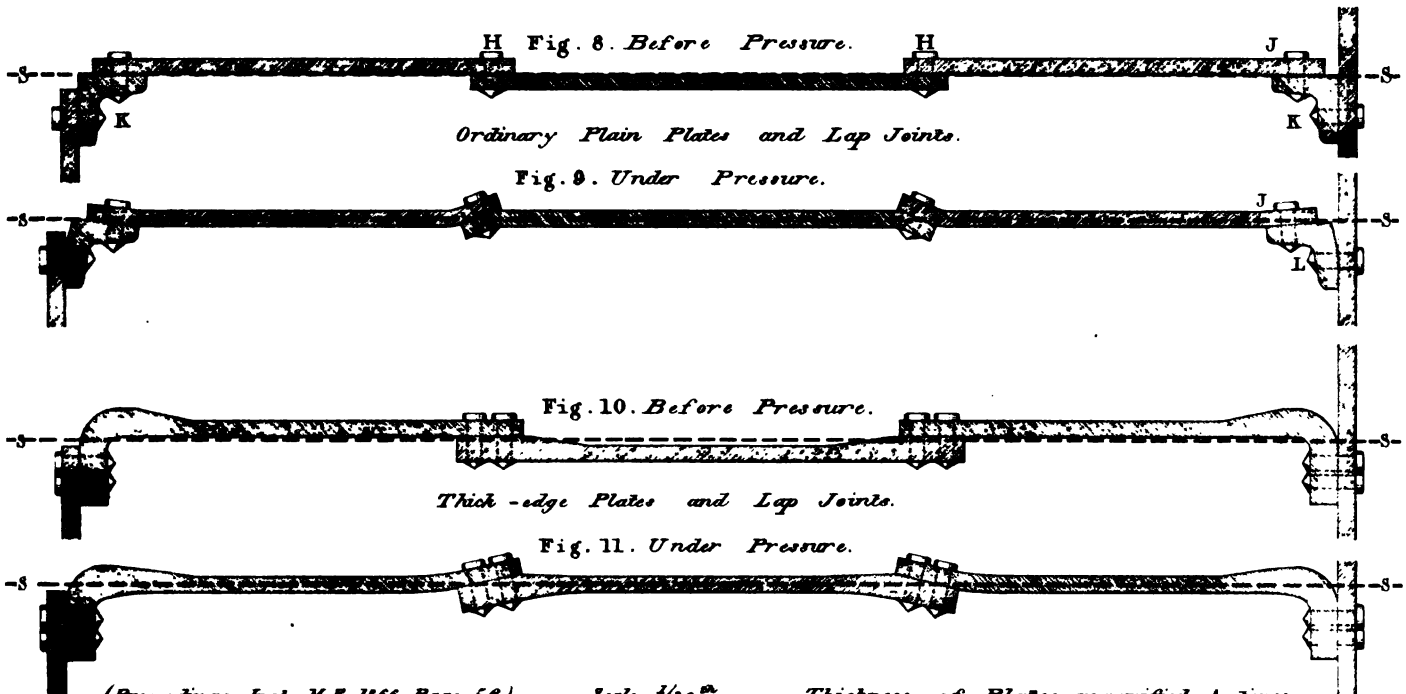


Fig. 8. *Before Pressure.*

Ordinary Plain Plates and Lap Joints.

Fig. 9. *Under Pressure.*

Fig. 10. *Before Pressure.*

Thick-edge Plates and Lap Joints.

Fig. 11. *Under Pressure.*

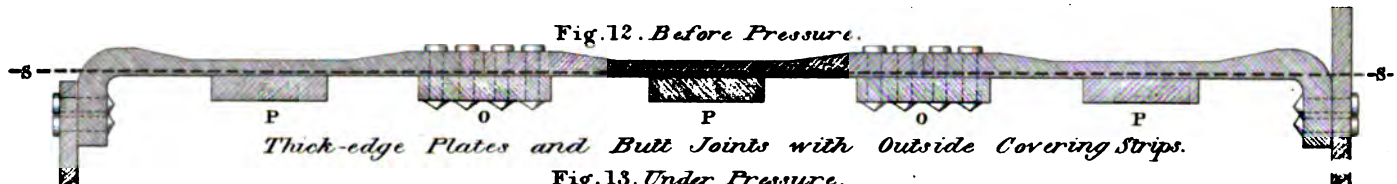
(Proceedings Inst. M.E. 1866. Page 56.) *Scale 1/20th* *Thickness of Plates magnified 4 times.*

CORROSION OF LOCOMOTIVE BOILERS.

Plate 15.

Diagrams showing line of Longitudinal Strain in Boiler Barrel, before pressure and under pressure.

Fig. 12. *Before Pressure.*



Thick-edge Plates and Butt Joints with Outside Covering Strips.

Fig. 13. *Under Pressure.*

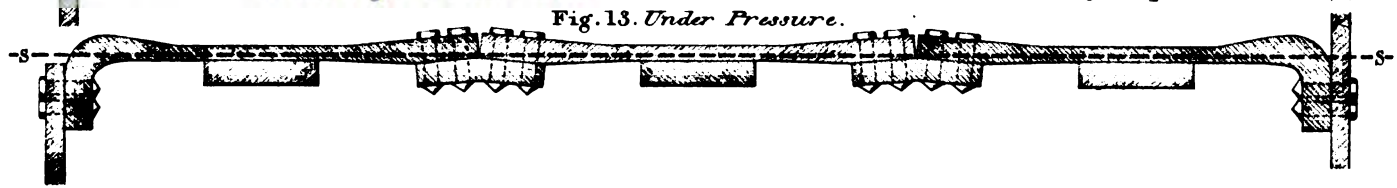
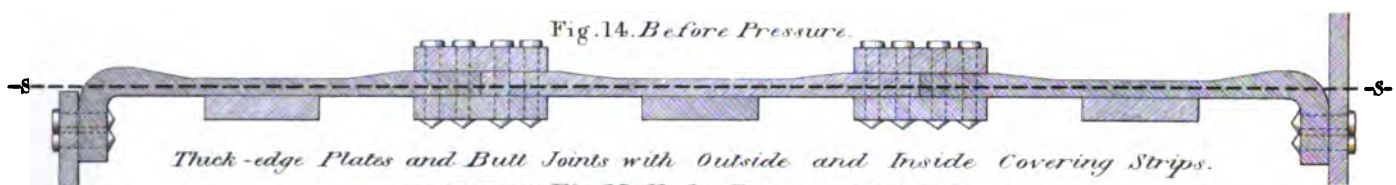
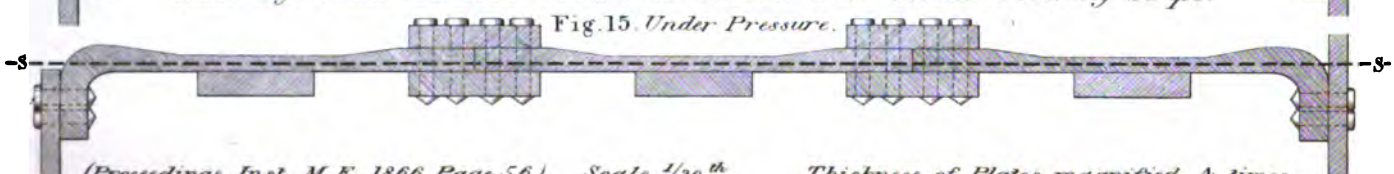


Fig. 14. *Before Pressure.*



Thick-edge Plates and Butt Joints with Outside and Inside Covering Strips.

Fig. 15. *Under Pressure.*



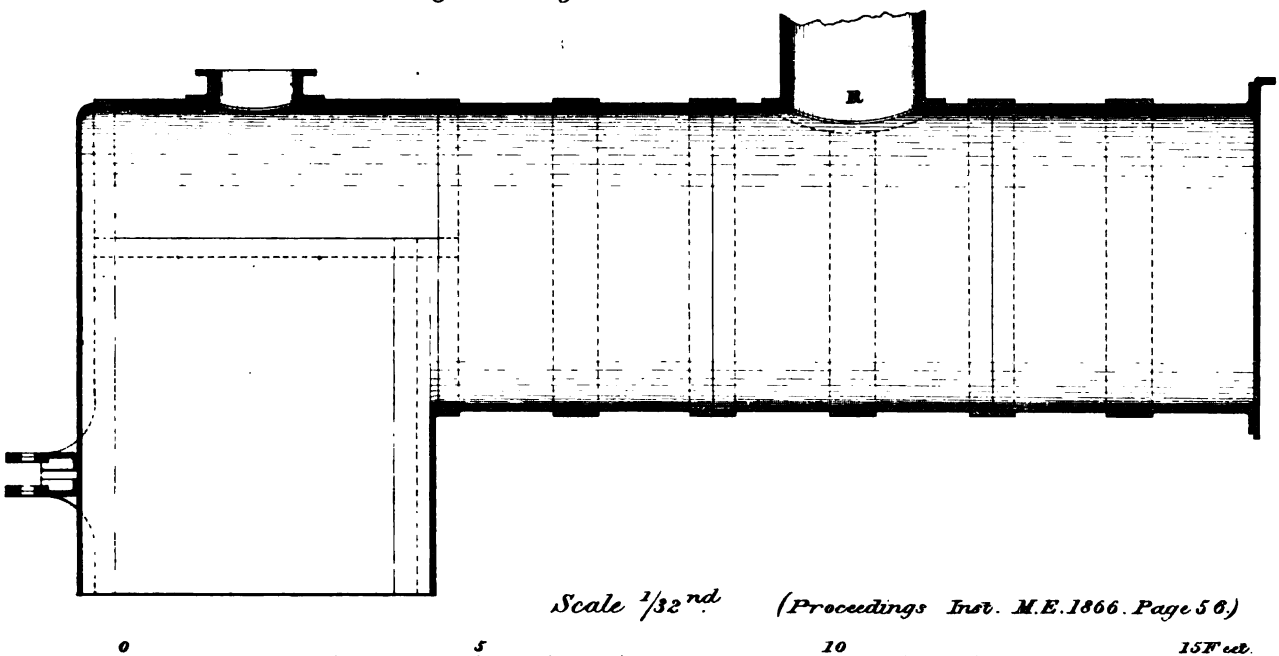
(Proceedings Inst. M.E. 1866. Page 56) *Scale 1/20th* *Thickness of Plates magnified 4 times.*

CORROSION OF LOCOMOTIVE BOILERS.

Plate 16.

WELDED BOILER WITH THICK-EDGE PLATES AND BUTT JOINTS.

Fig. 16. *Longitudinal Section.*



CORROSION OF LOCOMOTIVE BOILERS.

Plate 17.

WELDED BOILER WITH THICK-EDGE PLATES AND BUTT JOINTS.

Fig. 17. *Sectional Plan. Scale 1/32nd.*

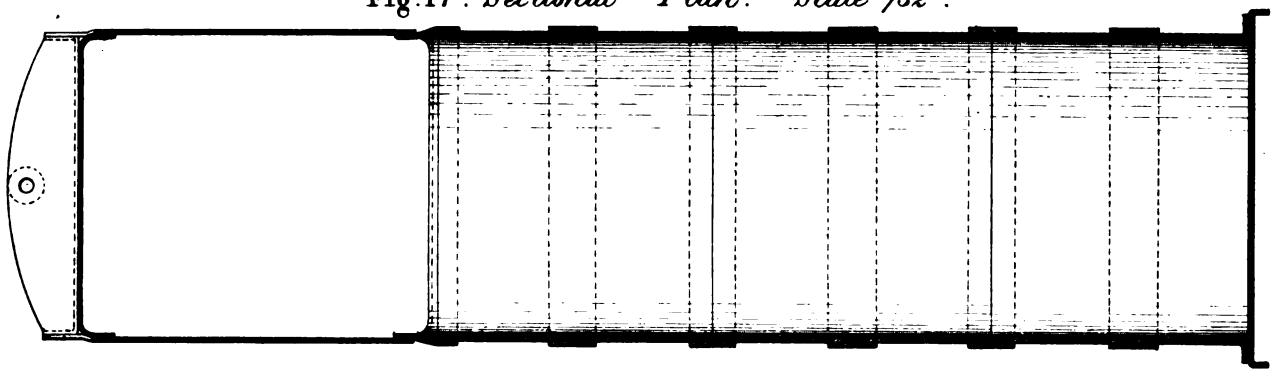


Fig. 18. *Enlarged Section of Thick-edge Plates, showing Butt Joints in Boiler Barrel. Scale 1/8th.*

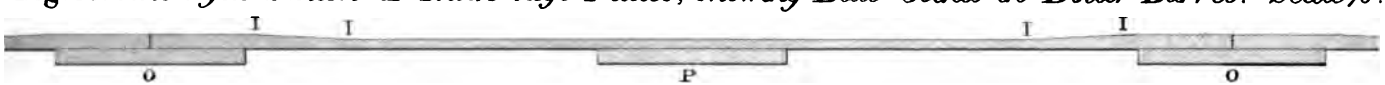
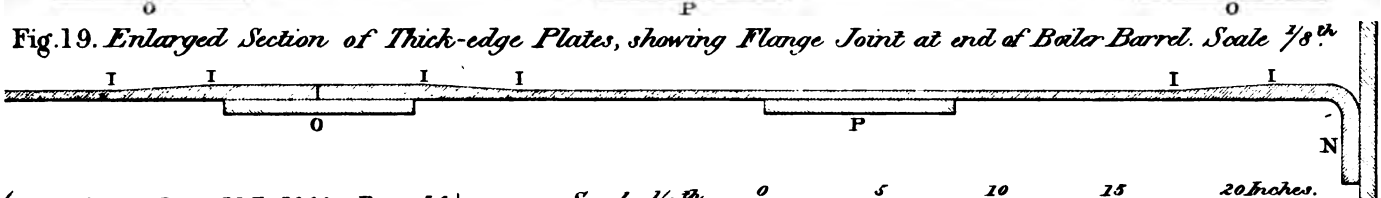


Fig. 19. *Enlarged Section of Thick-edge Plates, showing Flange Joint at end of Boiler Barrel. Scale 1/8th.*



(Proceedings Inst. M.E. 1866. Page 56.)

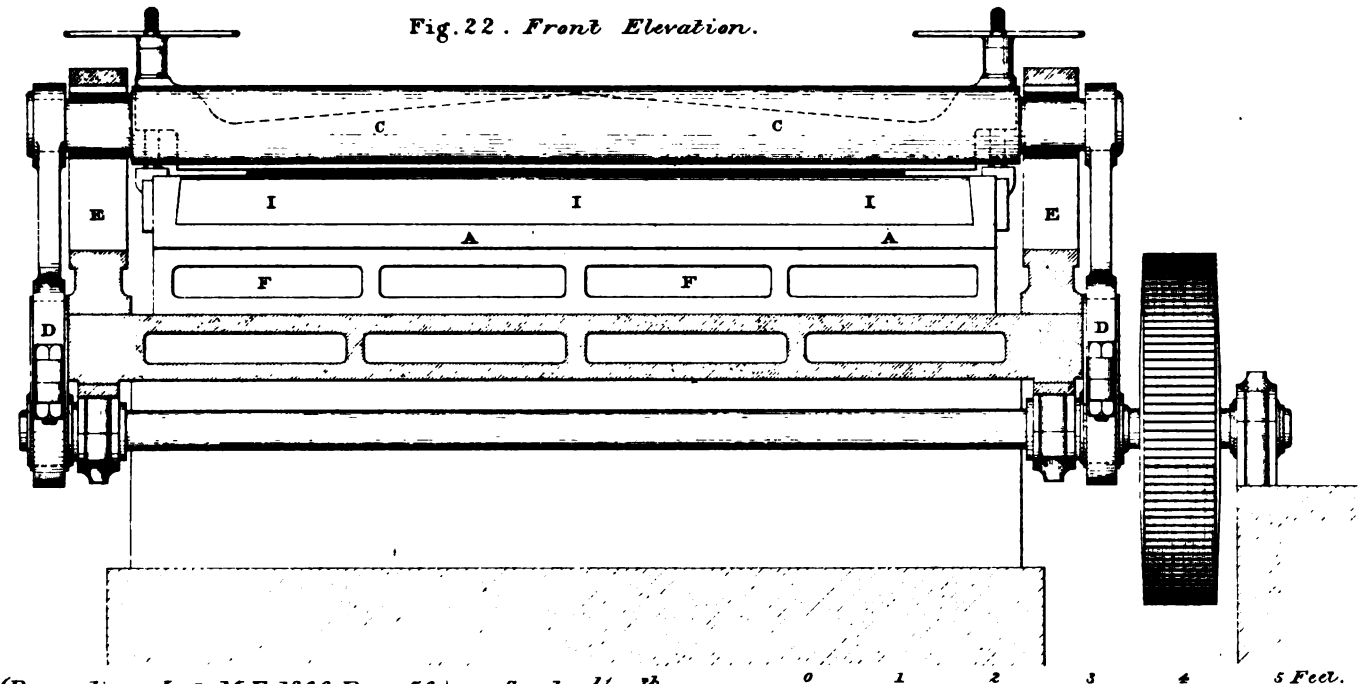
Scale 1/8th. 0 5 10 15 20 Inches.

CORROSION OF LOCOMOTIVE BOILERS.

Plate 19.

FLANGING MACHINE.

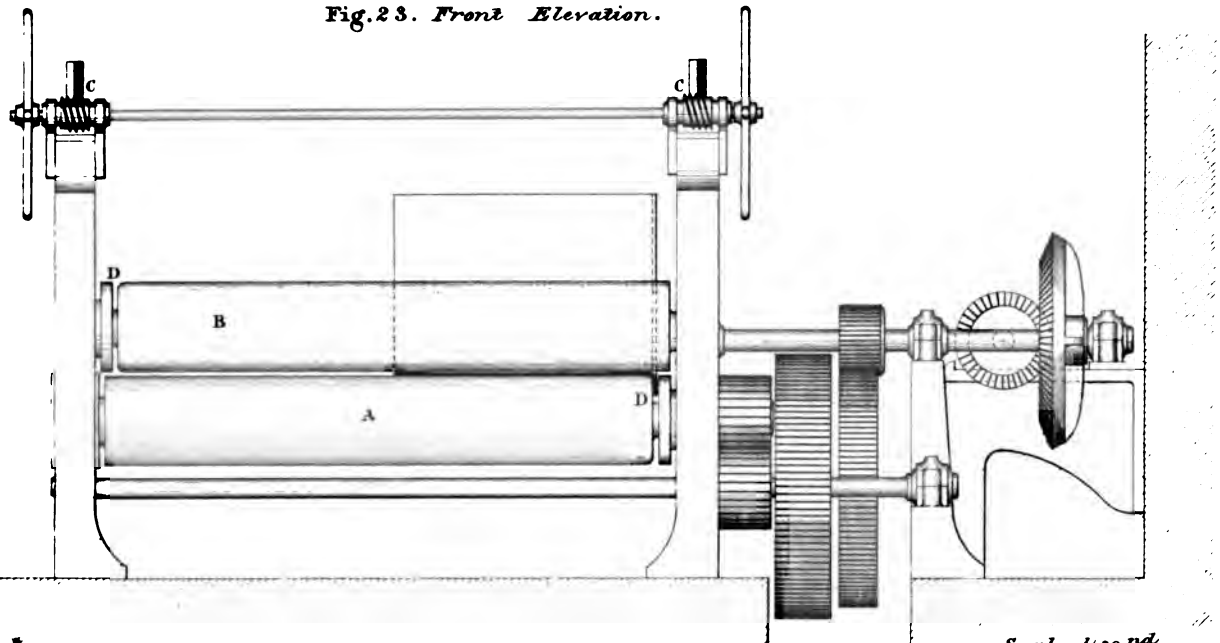
Fig. 22. *Front Elevation.*



(Proceedings Inst. M.E. 1866. Page 56.) *Scale 1/24th.*

BENDING MACHINE.

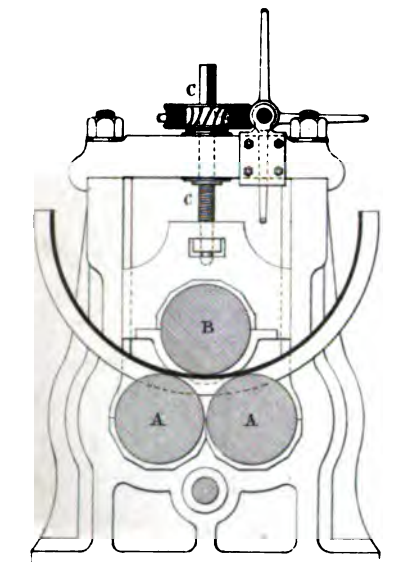
Fig. 23. *Front Elevation.*



(Proceedings Inst. M.E. 1866. Page 56.)

BENDING MACHINE.

Fig. 24. *Transverse Section.*



Scale 1/32nd

0 1 2 3 4 5 Feet.

(Proceedings Inst. M.E. 1866. Page 56.)

Fig. 25.

Section of Fluted Surface of Rolls.

Scale half full size.

Fig. 27. *End Elevation.*

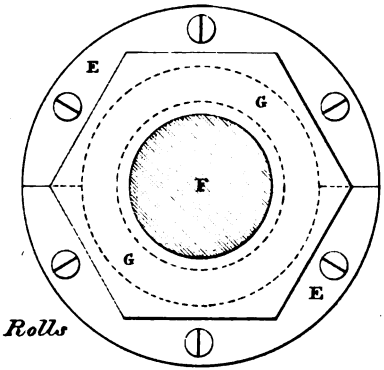


Fig. 26. *Section of Groove at end of Rolls to receive Flange of Plate.*

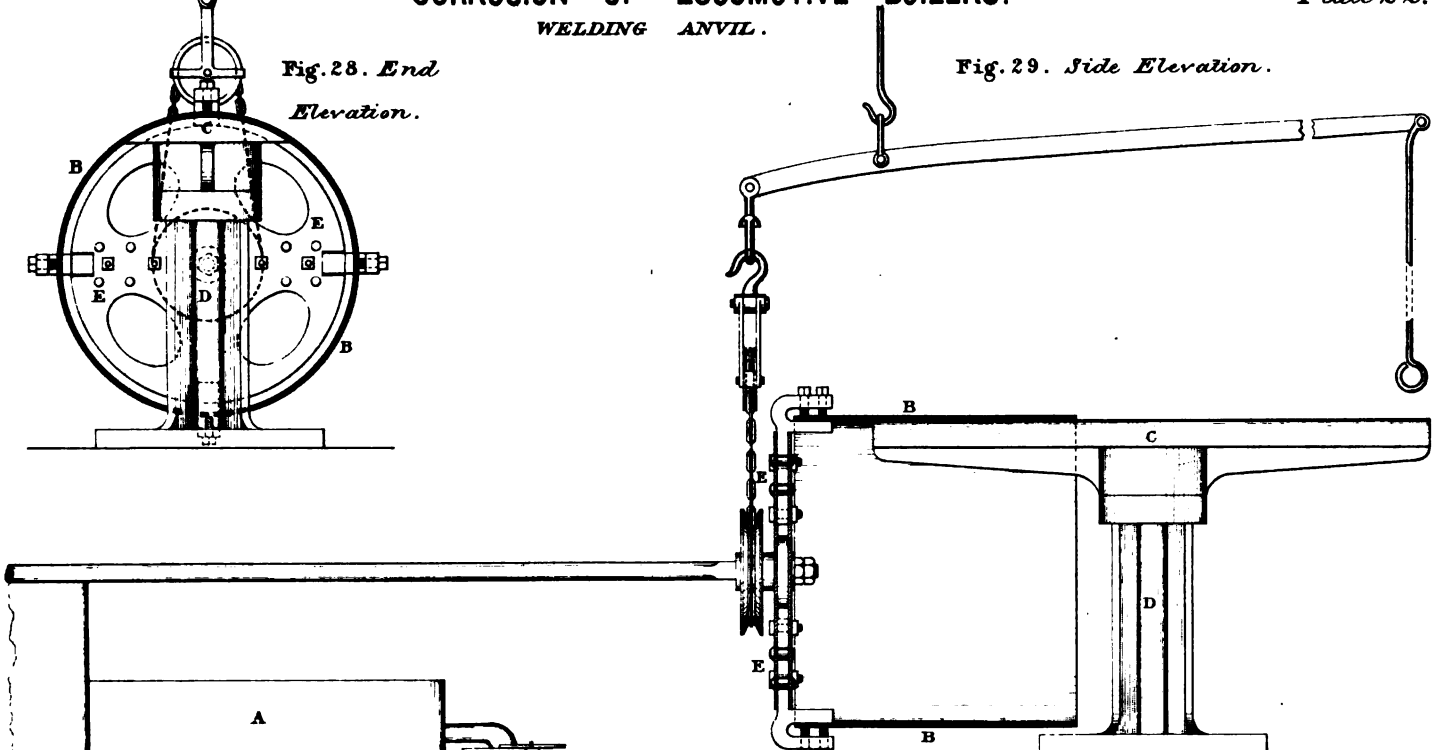
Scale 1/8th

CORROSION OF LOCOMOTIVE BOILERS.

WELDING ANVIL.

Fig. 28. *End Elevation.*

Fig. 29. *Side Elevation.*



(Proceedings Inst. M.E. 1866. Page 56.) Scale 1/32nd.

CORROSION OF LOCOMOTIVE BOILERS. *Plate 23.*

BLOCKING FURNACE.

Fig. 30. *Vertical Section.*

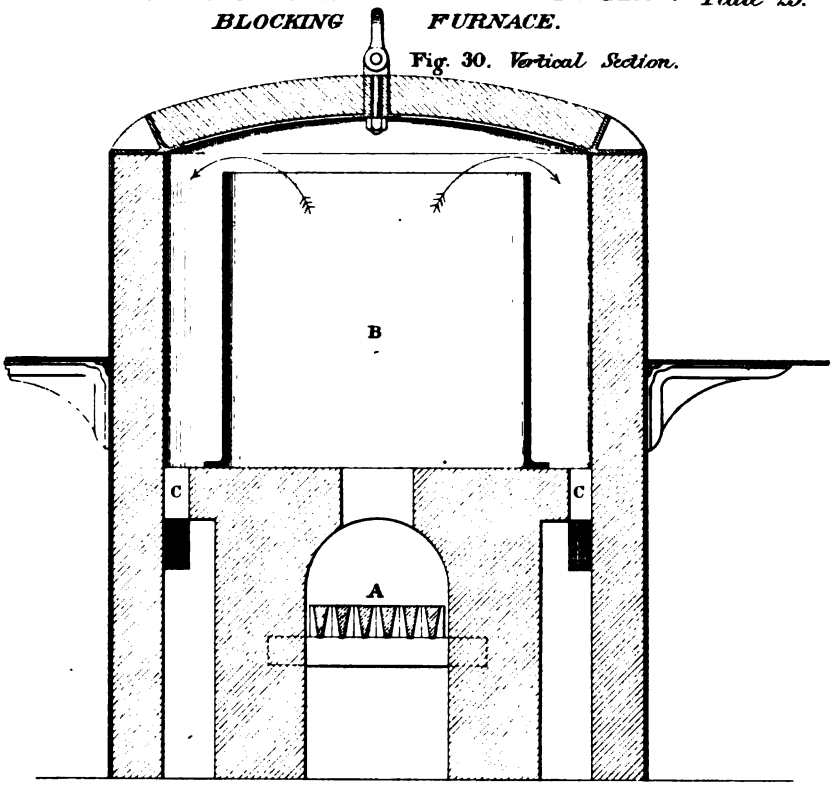
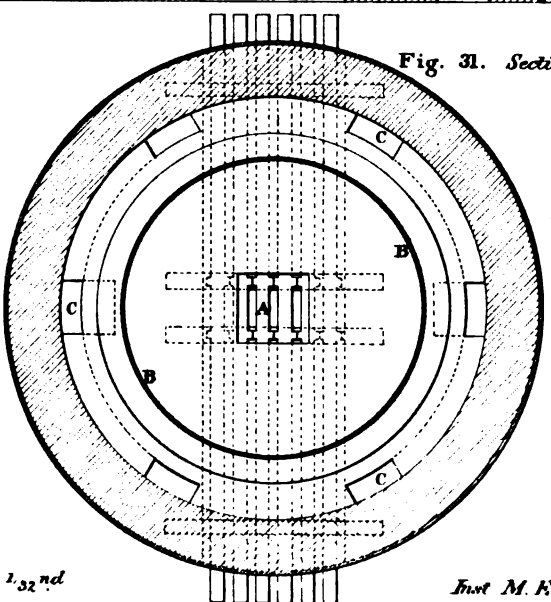


Fig. 31. *Sectional Plan.*



Scale 1/32nd

0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst M. E. 1866. Page 56)

CORROSION OF LOCOMOTIVE BOILERS. *Plate 24.*

BLOCKING PRESS.

Fig. 32. *Vertical Section.*

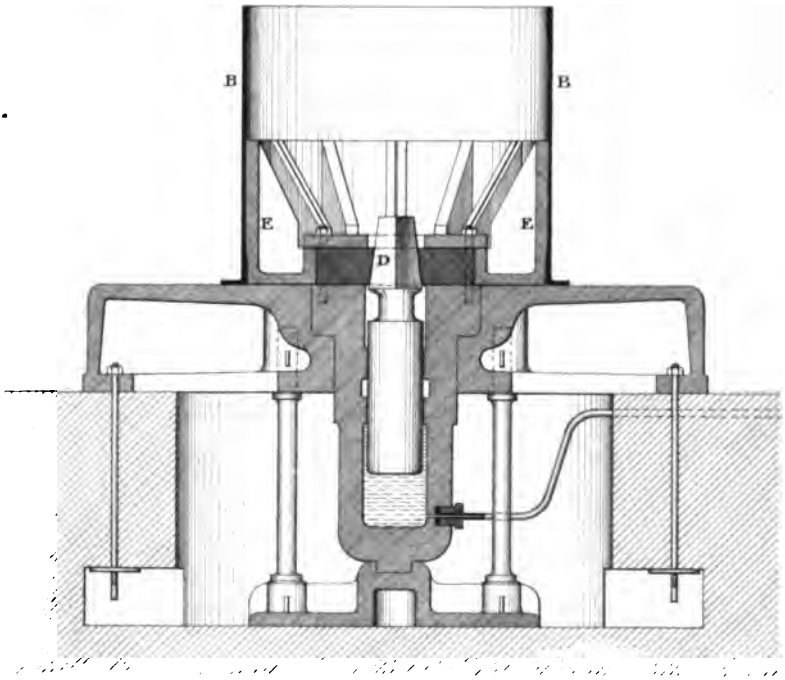
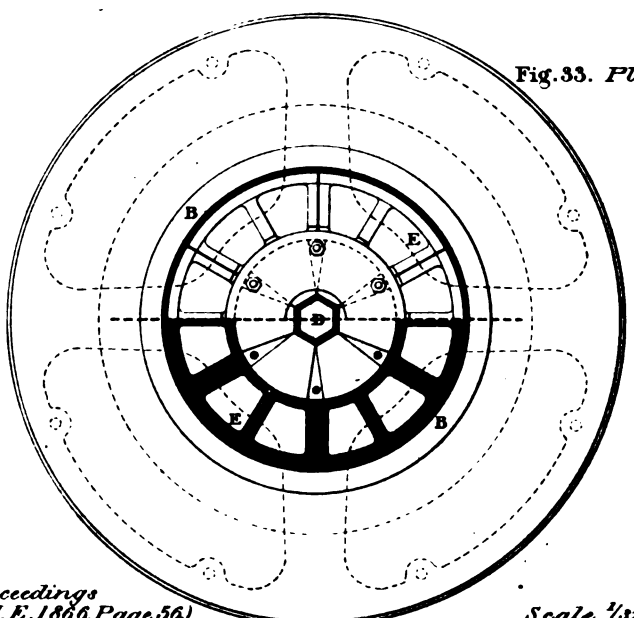


Fig. 33. *Plan.*



(Proceedings Inst. M.E. 1866. Page 56.)

Scale 1/32nd.

0 1 2 3 4 5 6 7 8 9 10 Feet.

IMPROVED LOCK AND KEY. *Plate 25.*

Elevations of Fenby's Lock, with two front cover plates removed.

Fig. 1. *Bolt shot. Bit inserted preparatory to unlocking.*

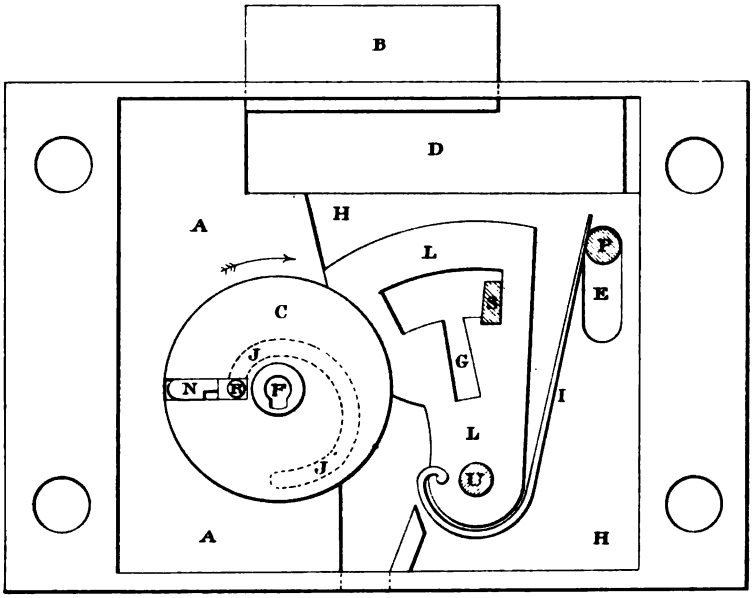
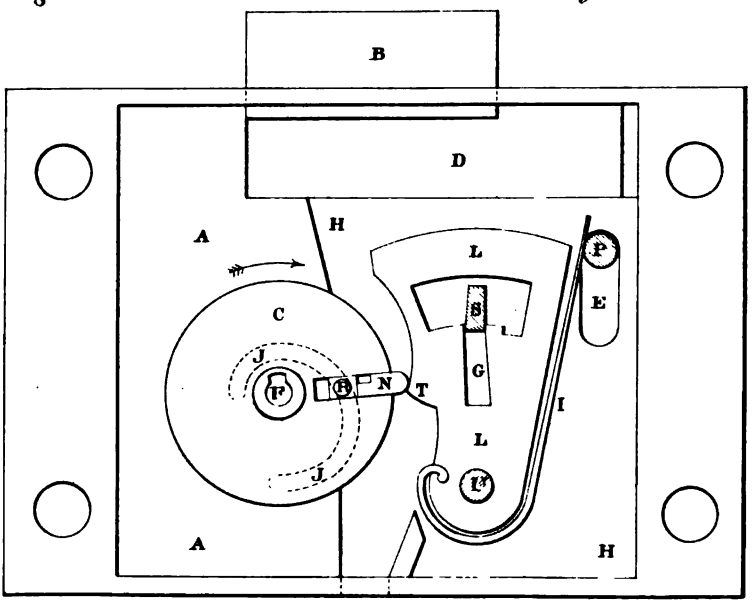


Fig. 2. *True Bit carried round, and raising Levers.*



(Proceedings Inst. M.E. 1866. Page 79.) *Scale 2/3rds full size.*

IMPROVED LOCK AND KEY. *Plate 26.*

Fig. 3. *True Bit falling inside the safe, after raising Levers ready for withdrawal of Bolt.*

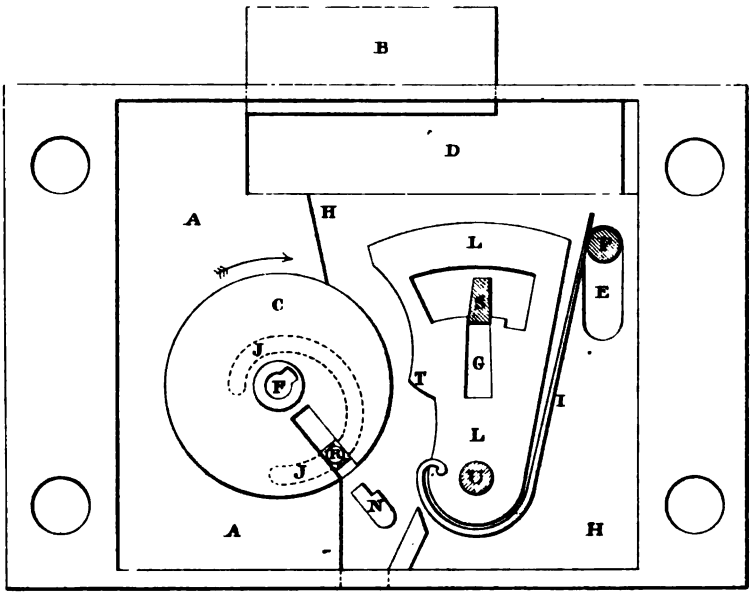
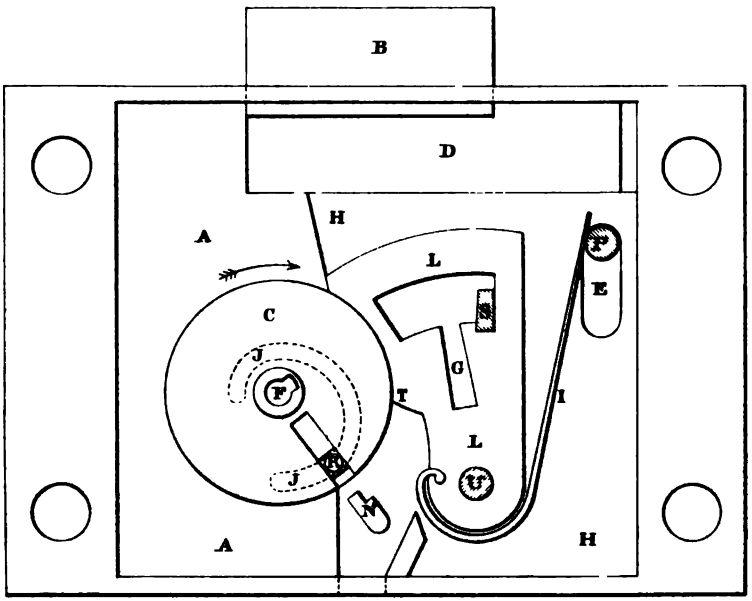


Fig. 4. *False Bit falling inside, after failing to raise Levers correctly.*



(Proceedings Inst. M.E. 1866. Page 73.) *Scale 2/3rds full size.*

Fig. 5. *Bolt withdrawn, after True Bit has fallen inside.*

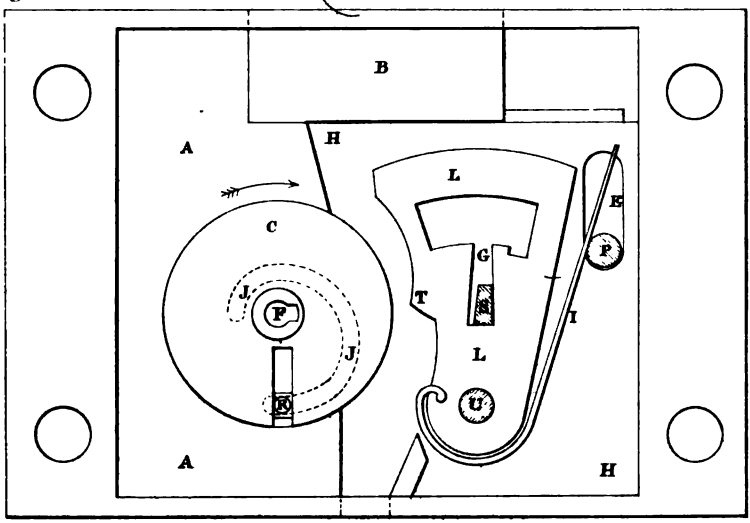


Fig. 6. *Main Bolt and Stump Bolt.*

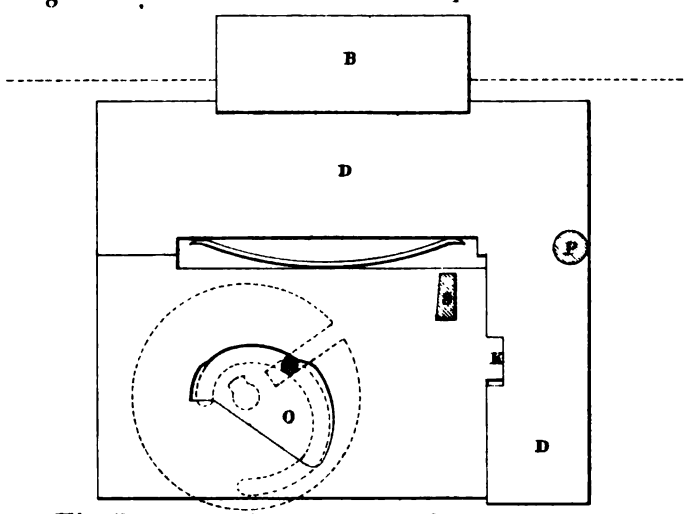
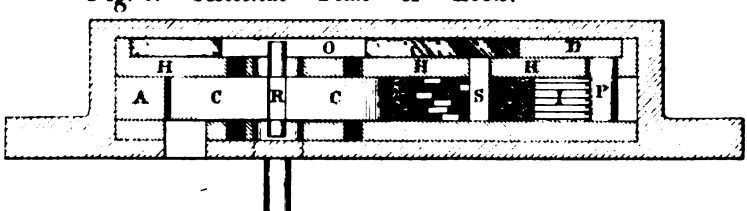


Fig. 7. *Sectional Plan of Lock.*



(Proceedings Inst. M.E. 1866. Page 79.) *Scale 2/3rds full size.*

IMPROVED LOCK AND KEY.

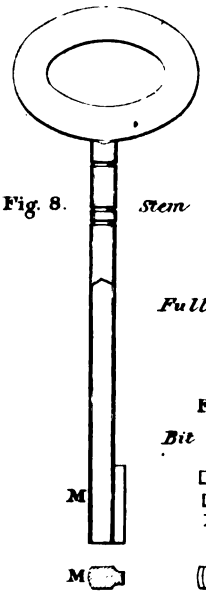


Fig. 8. *Stem of Key.*

Full size.

Fig. 9.
Bit of Key.

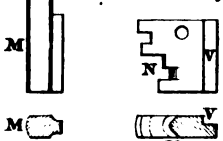


Fig. 10. *Transverse Section of Key Cutting Machine.*

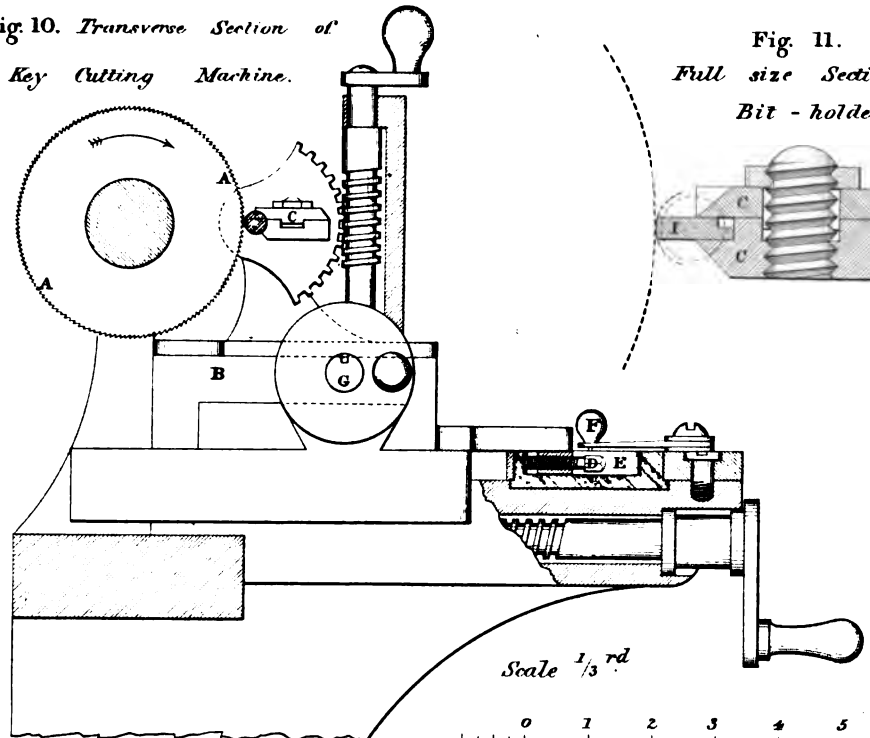
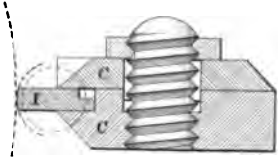


Fig. 11.
Full size Section of Bit - holder.



(*Proceedings Inst. M.E. 1866. Page 79.*)

IMPROVED LOCK AND KEY.

Plate 29.

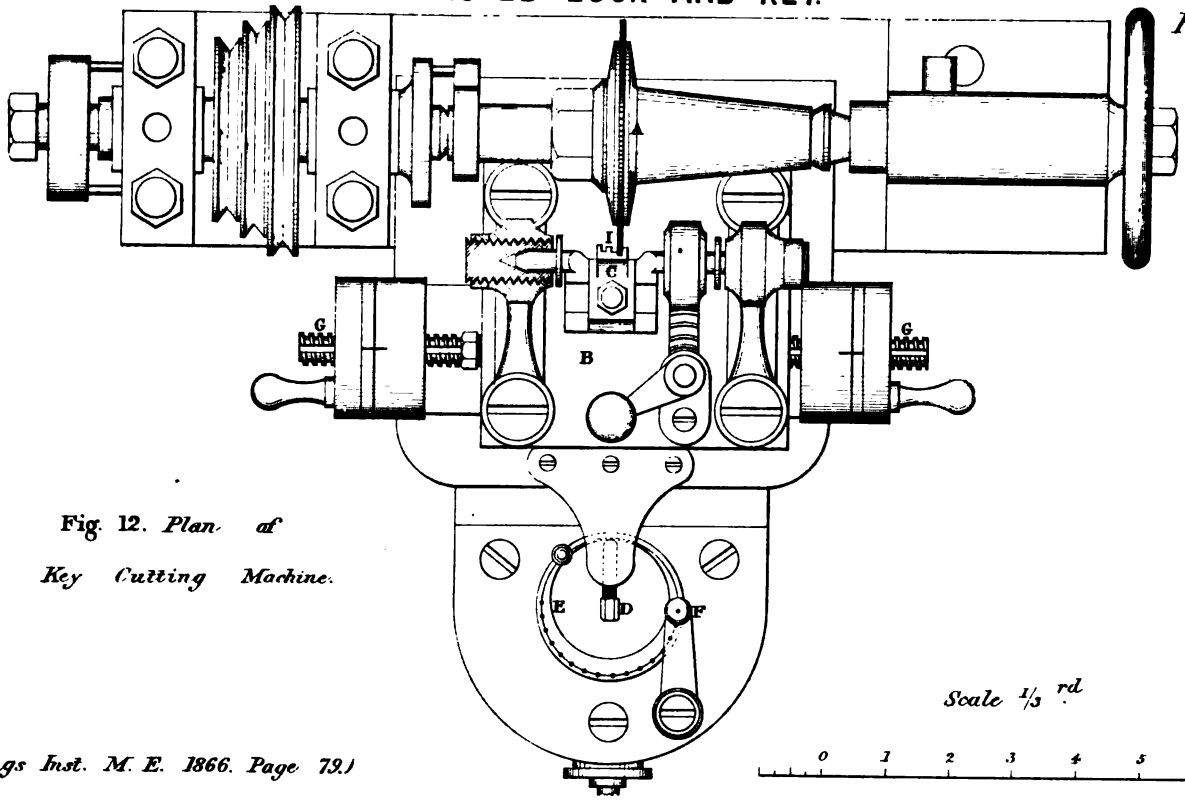


Fig. 12. *Plan of Key Cutting Machine.*

Scale 1/3 rd

0 1 2 3 4 5 6 Inches.

(Proceedings Inst. M. E. 1866. Page 79.)

IMPROVED LOCK AND KEY.

Plate 29.

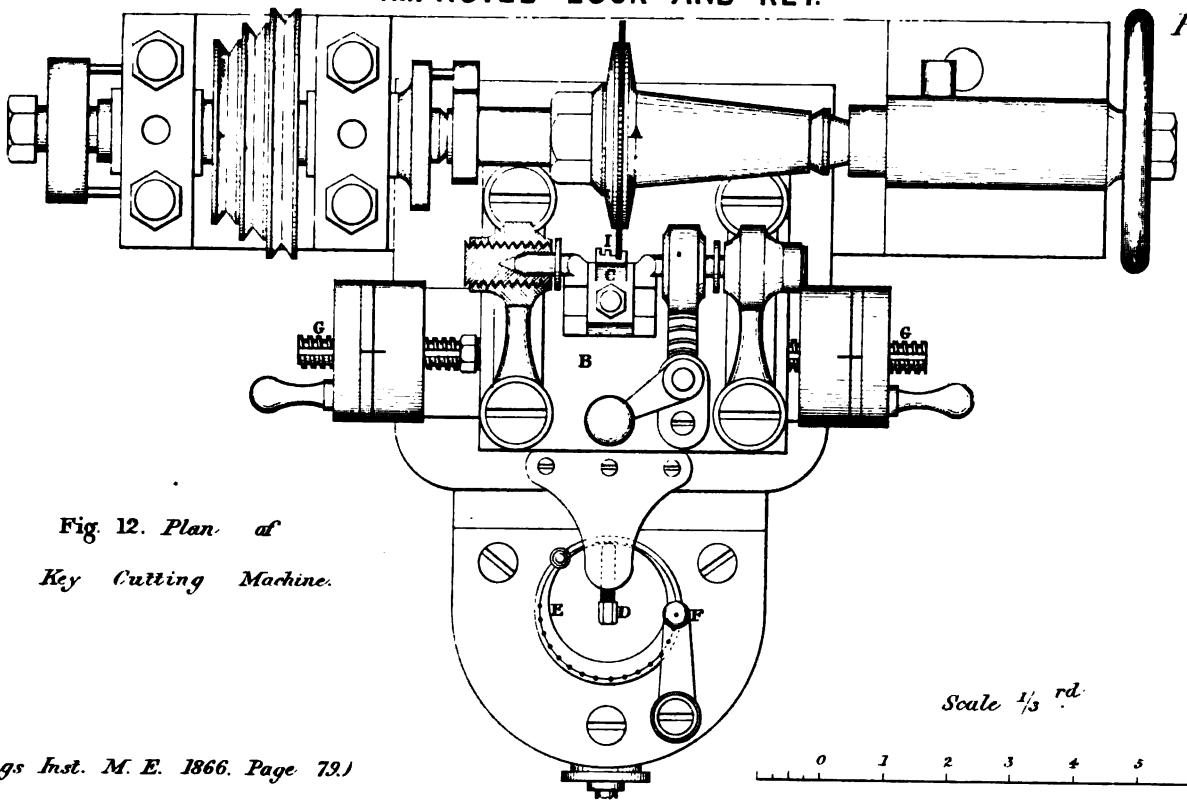


Fig. 12. *Plan of Key Cutting Machine.*

Scale 1/3 rd.

0 1 2 3 4 5 6 Inches.

(Proceedings Inst. M. E. 1866. Page 79.)

IMPROVED LOCK AND KEY. *Plate 30.*

Fig. 13. *Egyptian Lock.* *Scale 1/3 rd*

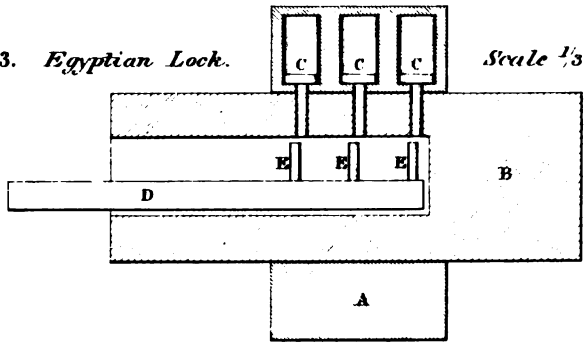


Fig. 14. *Lever Lock.* *Scale 2/3 rds*

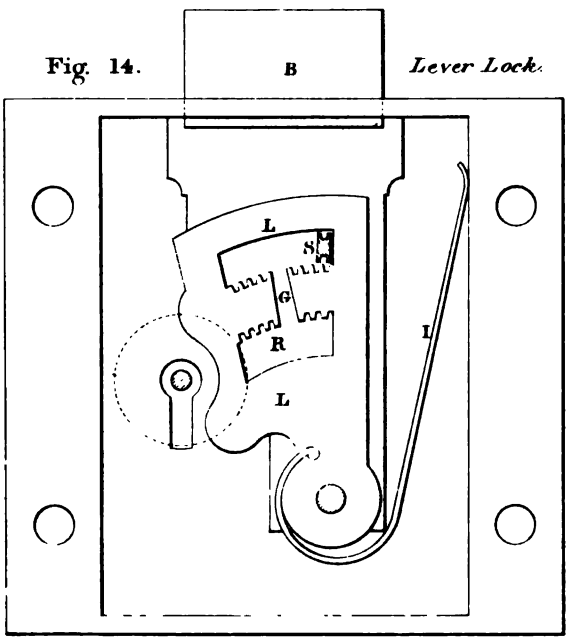
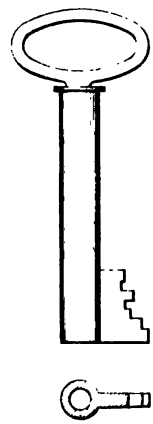


Fig. 15. *Key of Lever Lock.*



Picking Instrument for Lever Locks. *Scale 1/3 rd*

Fig. 16.

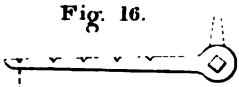


Fig. 17.

Fig. 18.

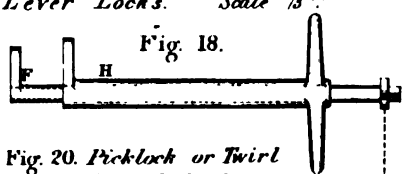


Fig. 19. *Key of Warded Lock.*

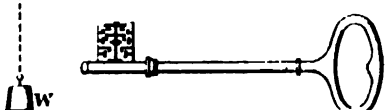
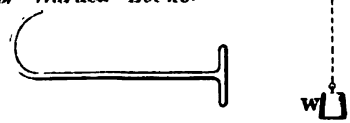


Fig. 20. *Picklock or Twirl for Warded Locks.*



(*Proceedings Inst. M. E. 1866. Page 79.*)

PROOF OF GUNS BY MEASUREMENT.

Plate 31.

Fig. 1. *Longitudinal Section of 7 inch Whitworth Gun, with Measuring Instrument placed in the bore.*

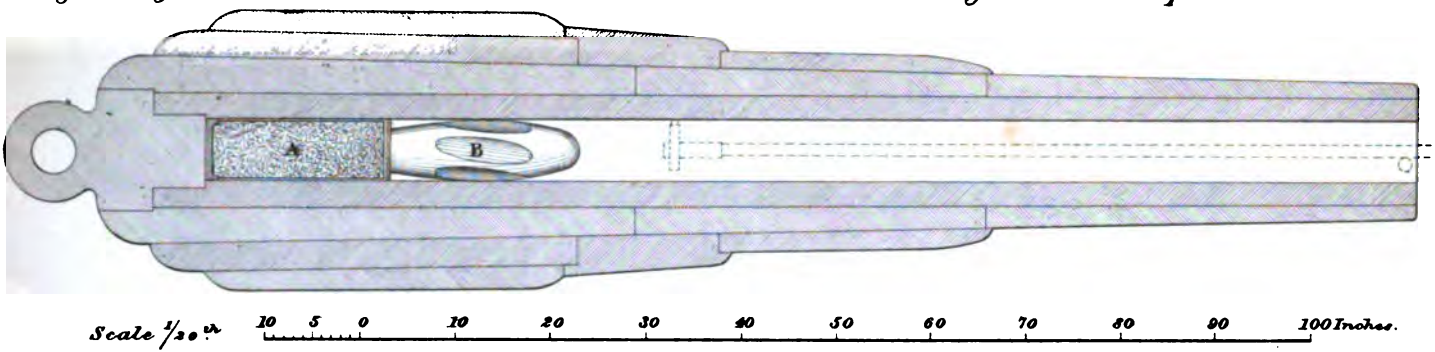


Fig. 2. *Plan of Shot.*

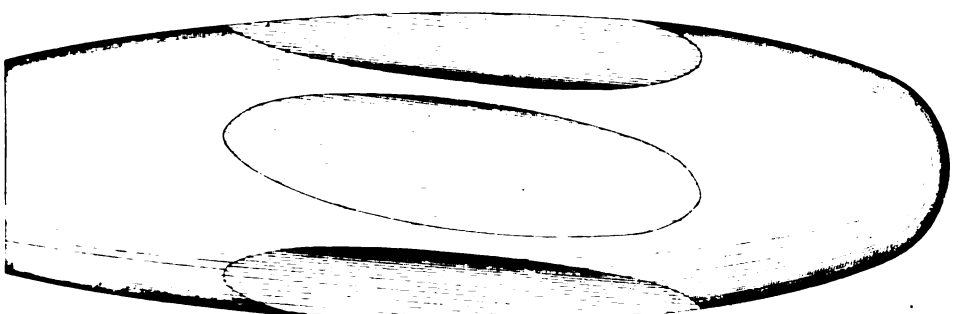
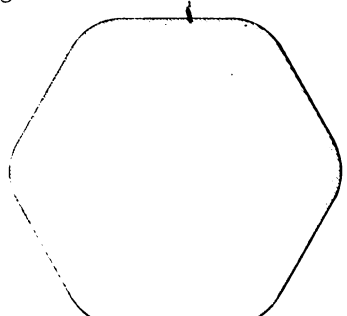


Fig. 3. *Transverse Section of Shot.*



(Proceedings Inst. M.E. 1866. Page 105.)

Scale 1/4th

PROOF OF GUNS BY MEASUREMENT.

Fig. 4. *Detail of Measuring Instrument.*

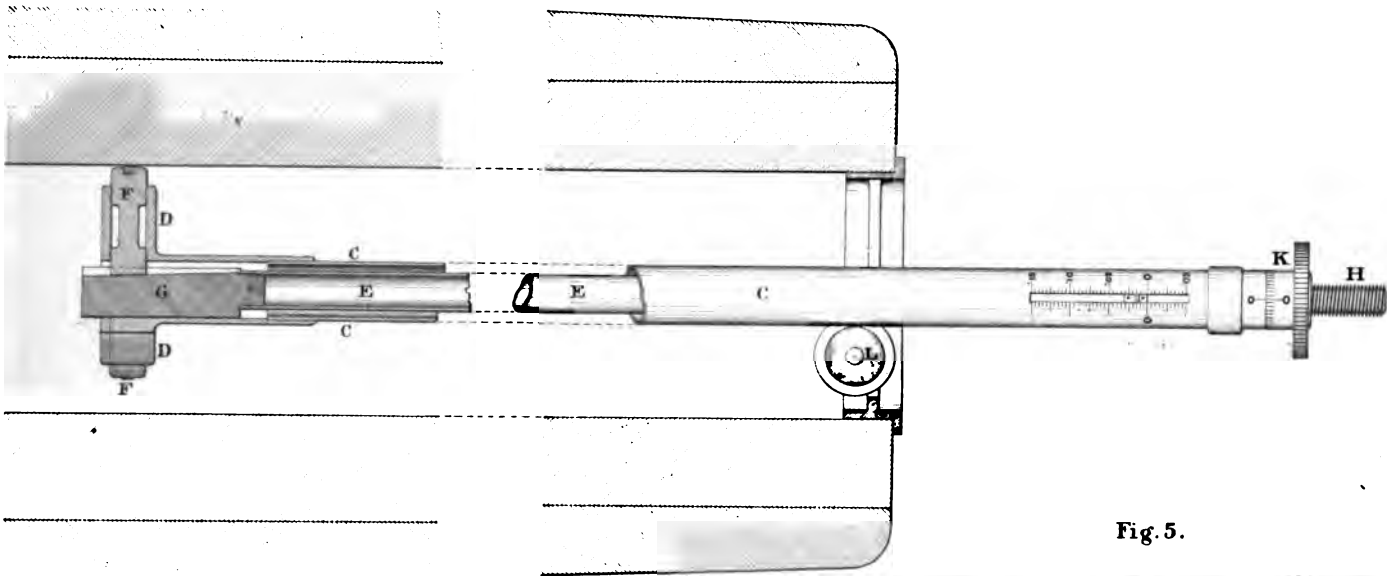


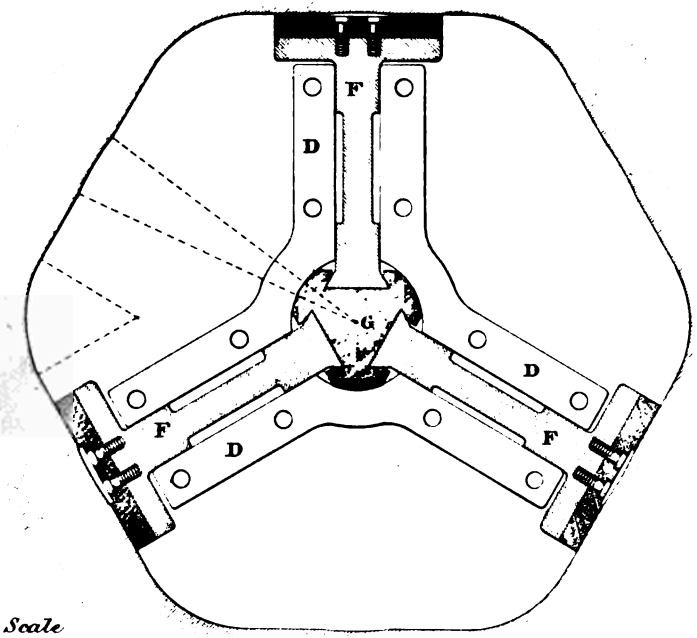
Fig. 5.

Scale 1/5th 0 5 10 15 Inches.

(Proceedings Inst. M.E. 1866. Page 105.)

PROOF OF GUNS BY MEASUREMENT.

Fig. 6. *Transverse Section of Measuring Instrument.*



Scale half full size.

Fig. 7. *Platinum Vent.* *Scale 1/15th*

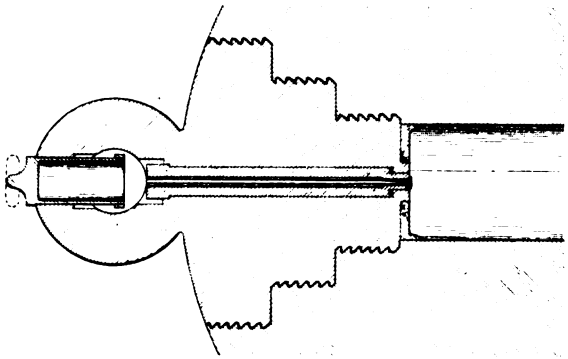
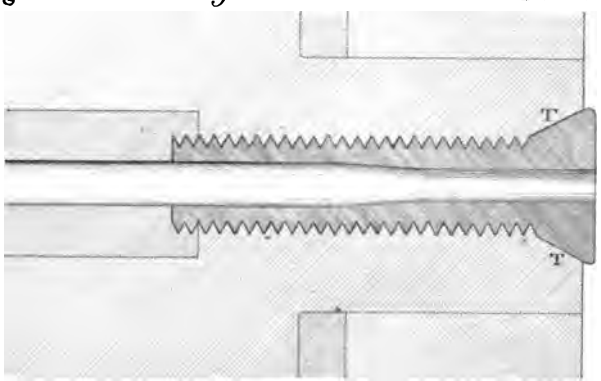


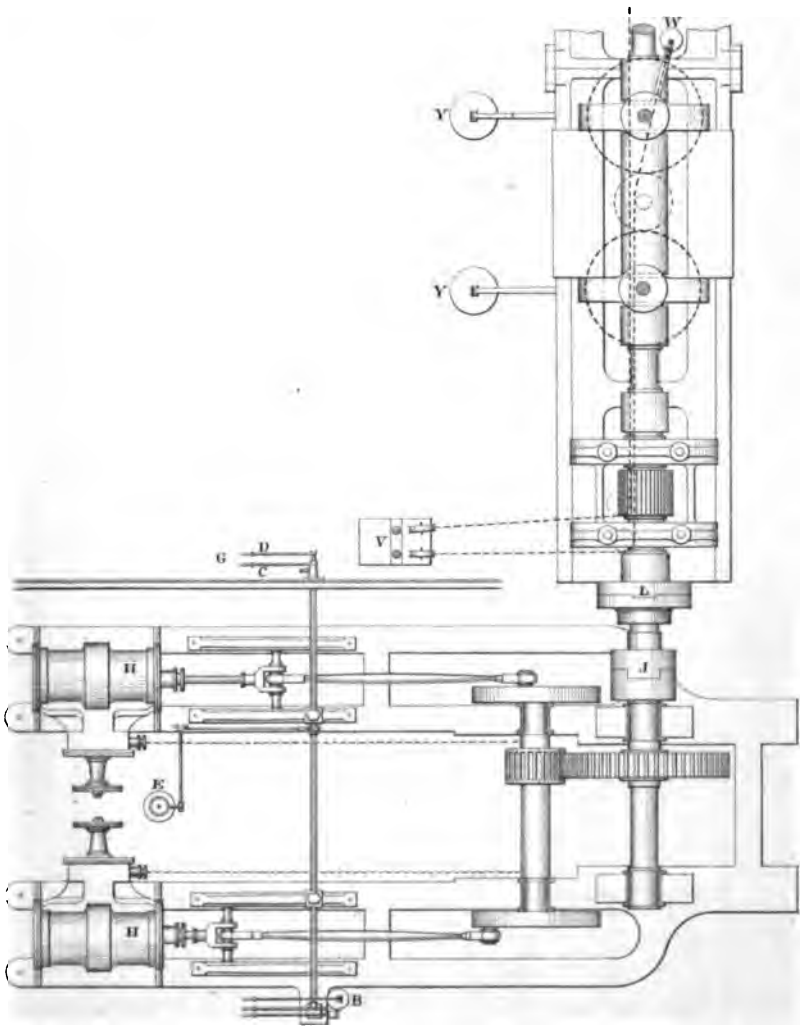
Fig. 8. *Full size Longitudinal Section of Vent Piece.*



(Proceedings Inst. M.E. 1866. Page 105.)

REVERSING ROLLING MILL. *Plate 34.*

Fig. 1. *General Plan of Rolling Mill and Engines.*



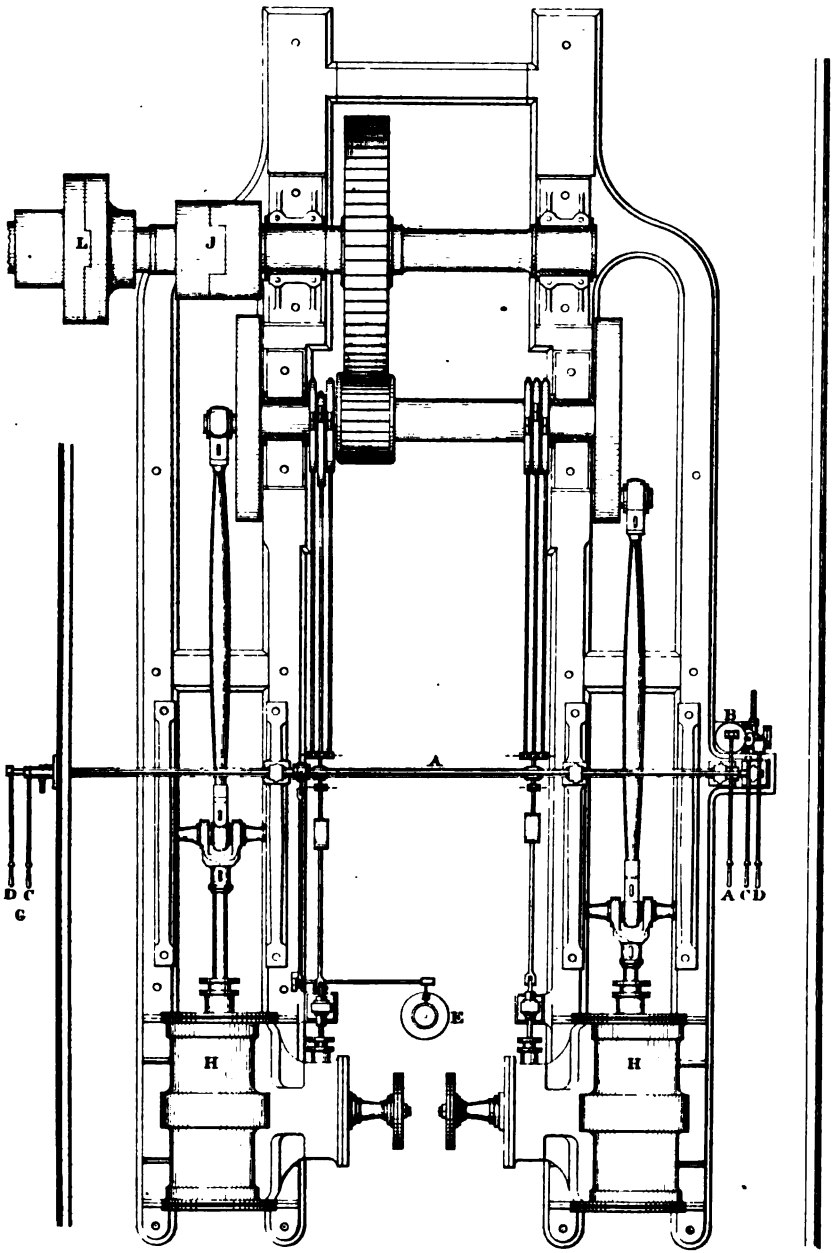
Scale 1/100 th

0 5 10 15 20 25 30 Feet

(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL. *Plate 35.*

Fig. 2. *Enlarged Plan of Engines.*



Scale 1/60 *th.* 0 5 10 15 *Feet.*

(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

Plate 36.

Fig. 3. *Side Elevation of Engines.*

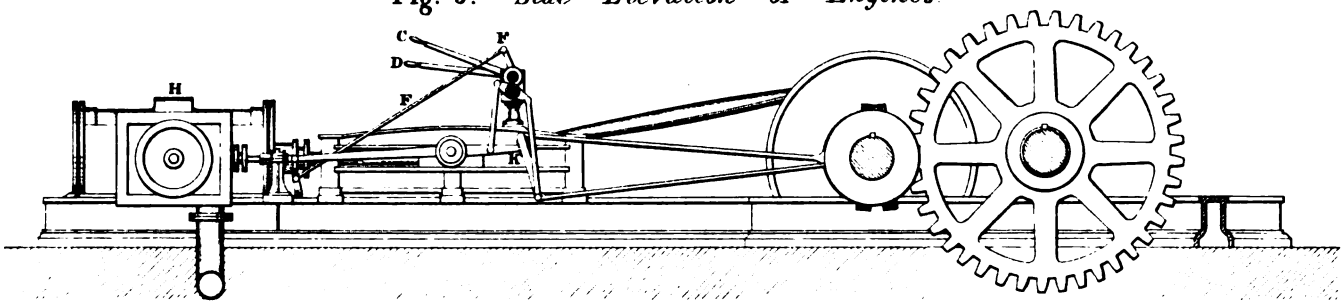
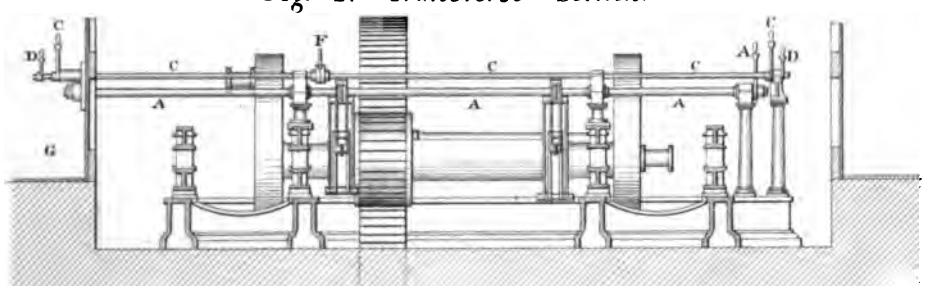


Fig. 4. *Transverse Section.*



(Proceedings Inst. M. E. 1866. Page 115.) *Scale* $\frac{1}{40}$ *th.*

0 5 10 15 20 *Feet.*

Fig. 5. *Link Motion.*
Scale 1/20th

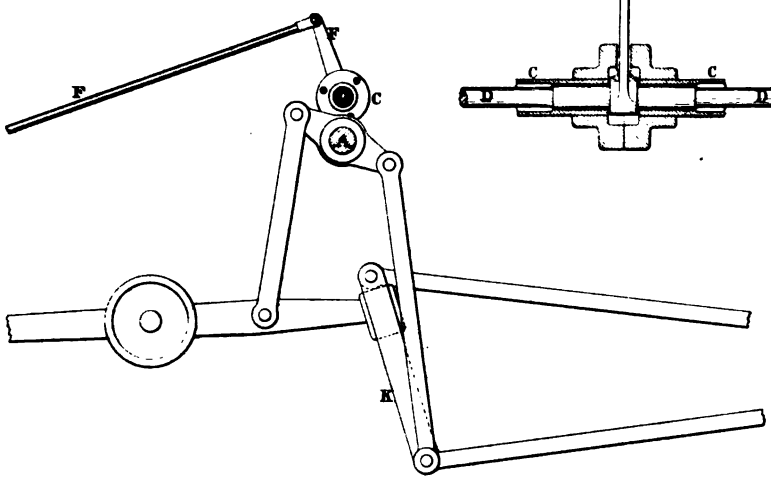


Fig. 6. *Scale 1/20th*

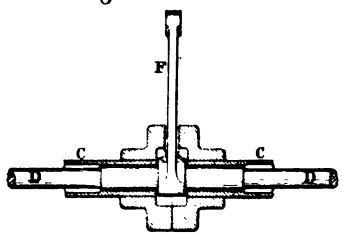
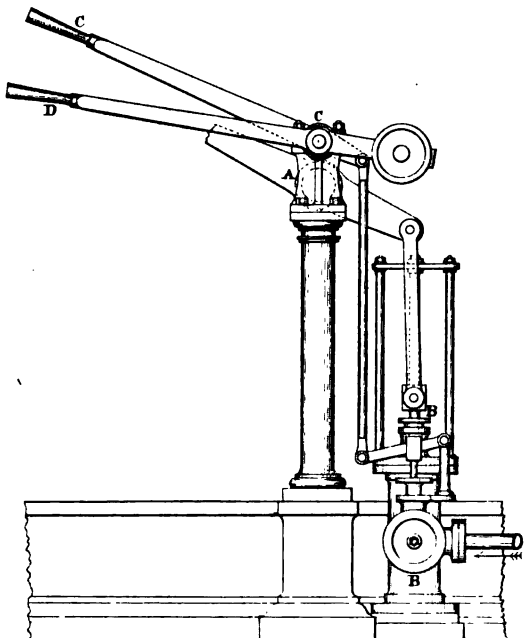


Fig. 7. *Hydraulic Reversing Gear.*
Scale 1/20th



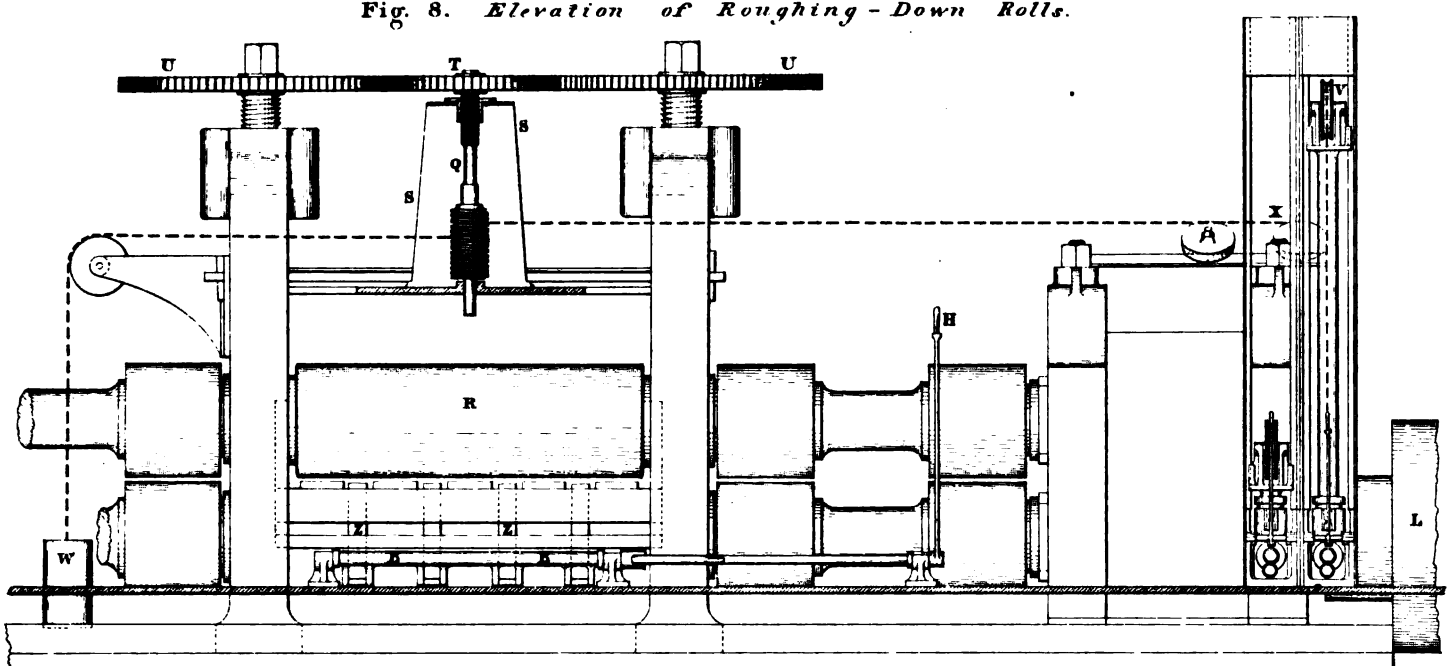
Scale 1/20th 10 5 0 10 20 30 40 50 *Inches.*

(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

Plate 38.

Fig. 8. *Elevation of Roughing-Down Rolls.*

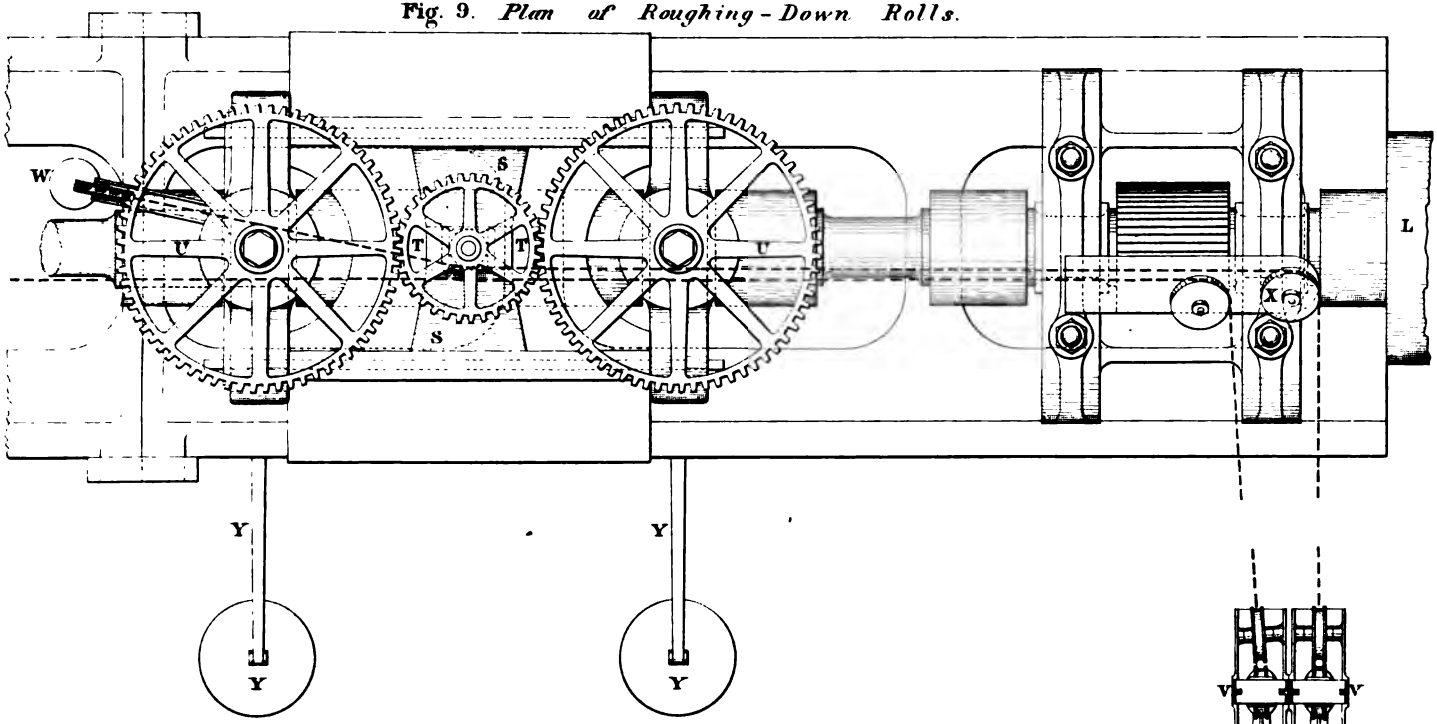


(Proceedings Inst. M. E. 1866. Page 115.) Scale 1/40th

0 1 2 3 4 5 6 7 8 9 10 Feet.

REVERSING ROLLING MILL.

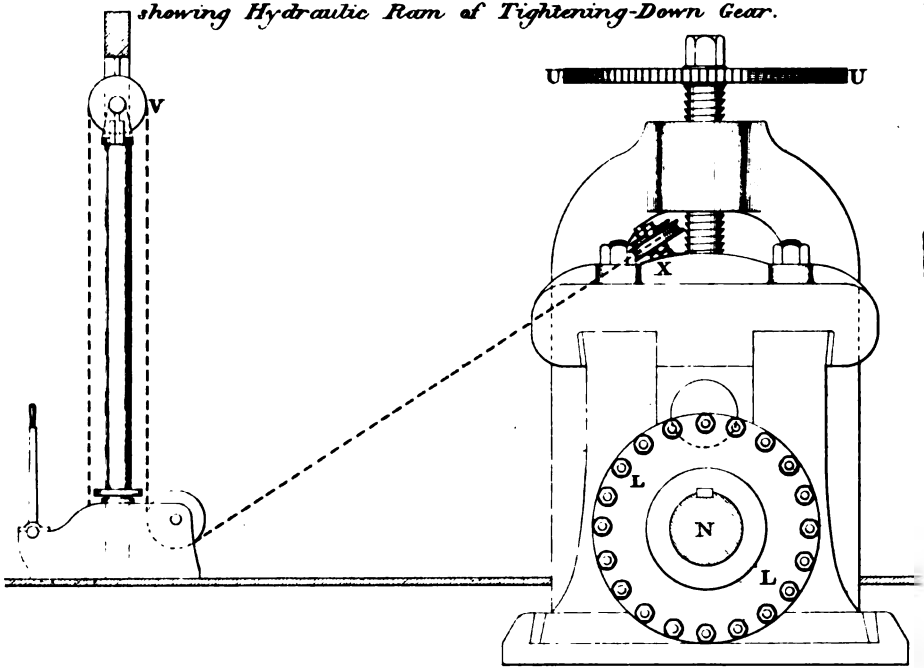
Fig. 9. *Plan of Roughing-Down Rolls.*



Scale 1/40th 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M. E. 1866. Page 115.)

Fig. 10. *End Elevation of Rolling Mill, showing Hydraulic Ram of Tightening-Down Gear.*

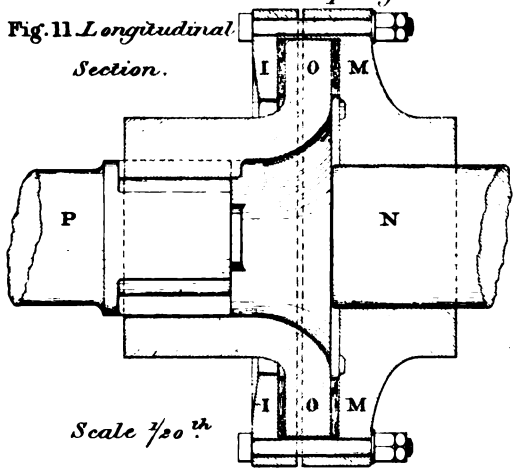


Scale 1/20th 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1866. Page 115)

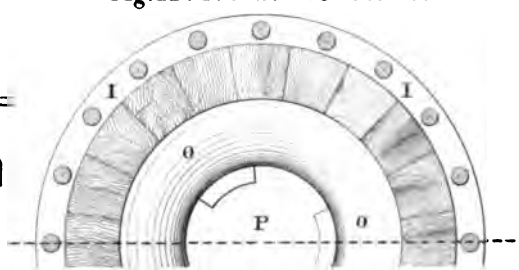
Friction Coupling.

Fig. 11. *Longitudinal Section.*



Scale 1/20th

Fig. 12. *Transverse Section.*



REVERSING ROLLING MILL.

Fig. 13. *Transverse Section through Housing.*

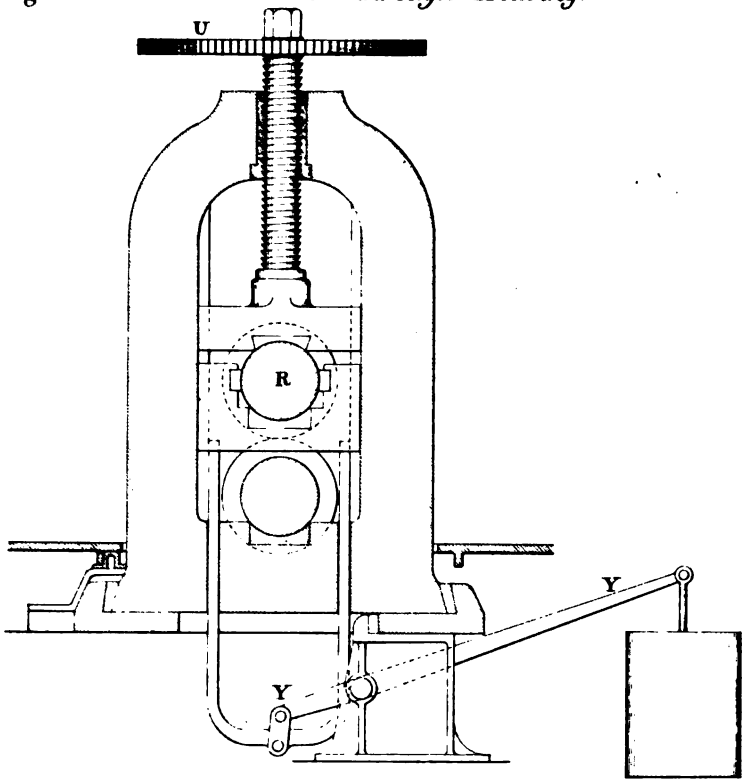
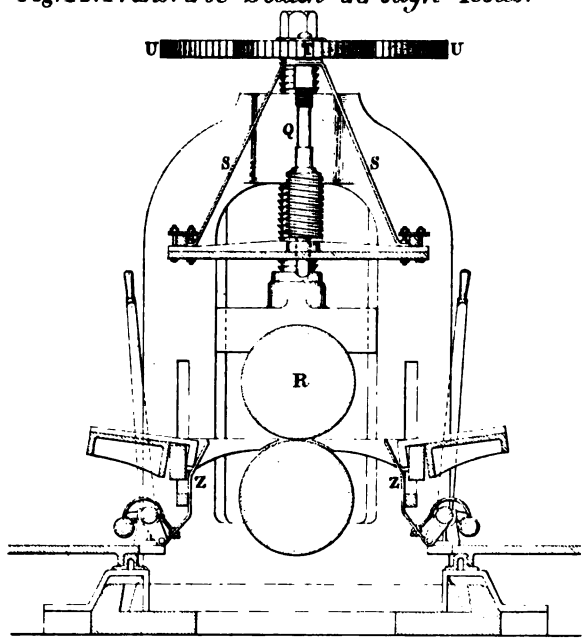


Fig. 14. *Transverse Section through Rolls.*



Scale 1/40th

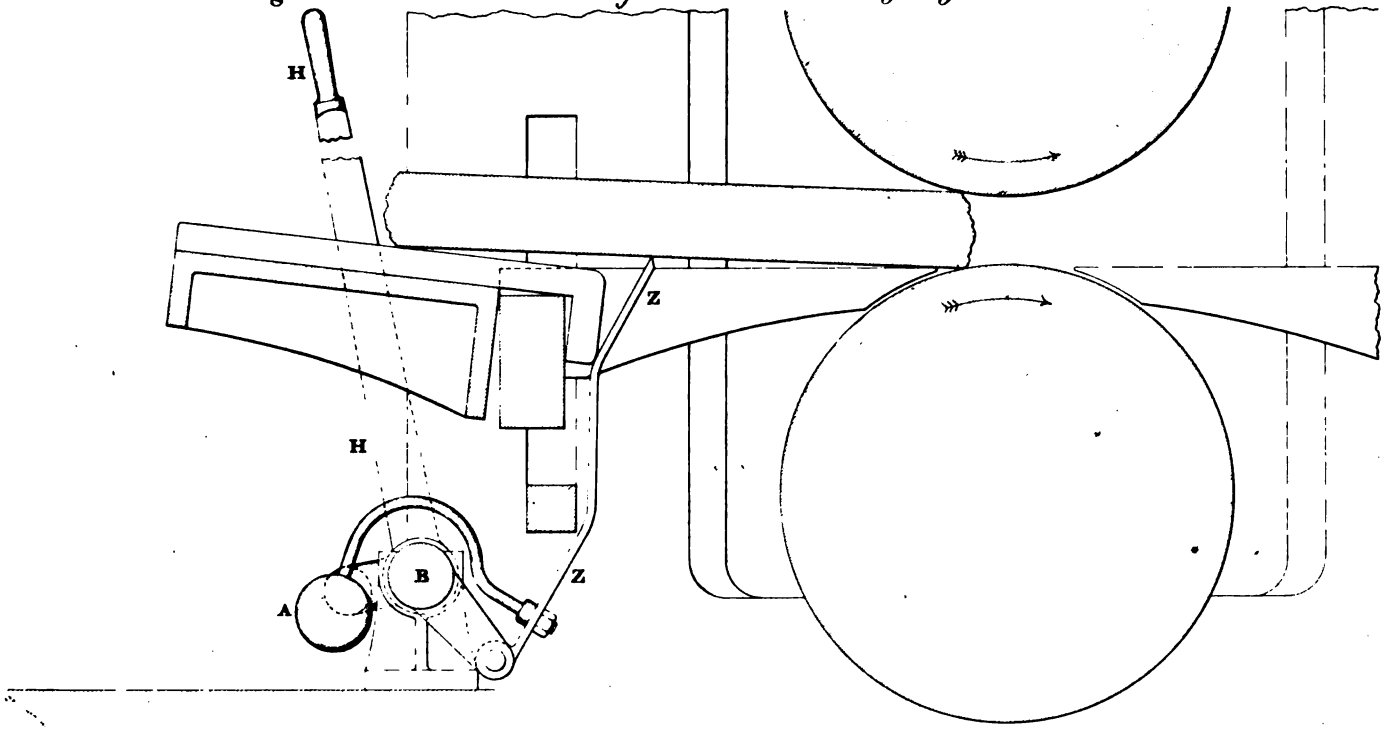
0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1866. Page 115.)

REVERSING ROLLING MILL.

Plate 42.

Fig. 15. *Levers for entering Slabs into Roughing-Down Rolls.*

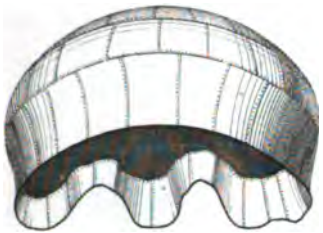


(Proceedings Inst. M.E. 1866. Page 115.)

Scale 1/10th.

BOILER EXPLOSIONS.

Fig. 1. *Haystack Boiler exploded from want of stays. Diam. 14′ 0″ Wednesbury 1862.*



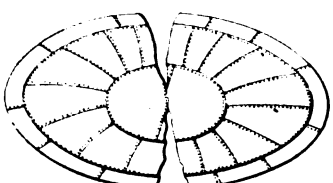
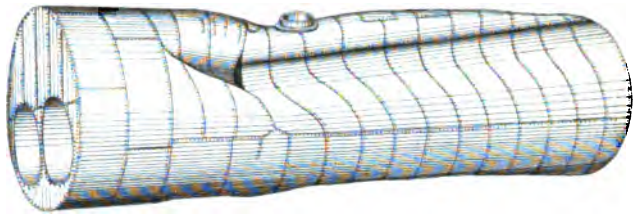


Fig. 4. *Lancashire Boiler collapsed by vacuum. Length 30′ 0″ Diam. 8′ 5″ Bury 1865.*



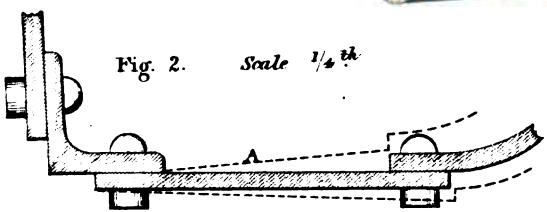


Fig. 2. *Scale 1/4th*

Fig. 3.

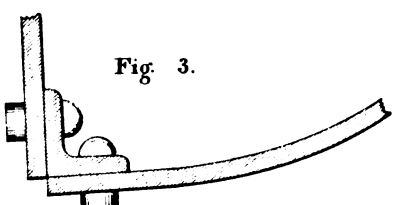
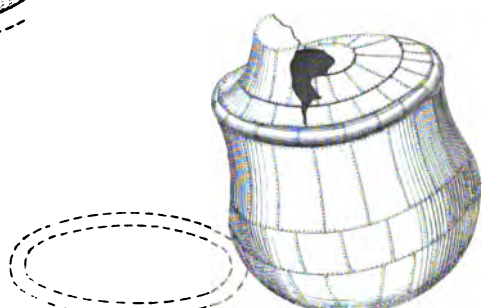
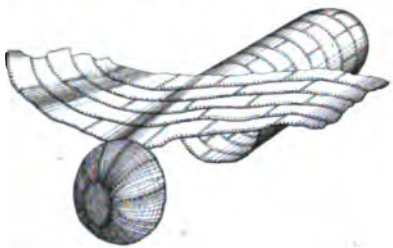


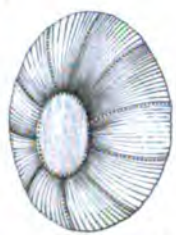
Fig. 5. *Haystack Boiler exploded from want of stays. Diam. 12′ 0″ Smethwick 1862.*



(Proceedings Inst. M.E. 1866. Page 130.)

Fig. 6. *Plain Cylindrical Boiler exploded from injury over fireplace. Length 34'0" Diam. 5'6" Darlaston 1863.*





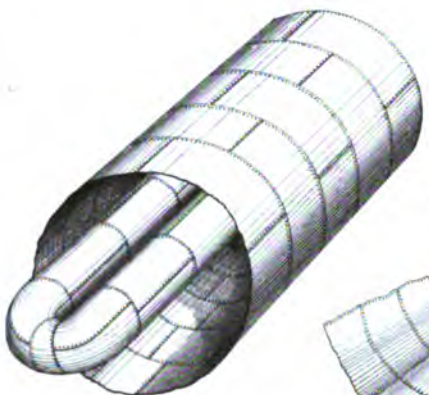


Fig. 7. *Three-Furnace Upright Boiler exploded from corrosion of bottom. Height 17'4" Diam. 9'0" Westbromwich 1864.*

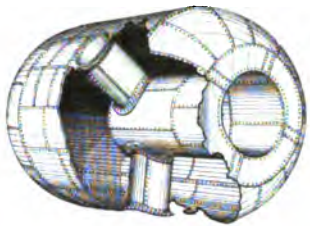
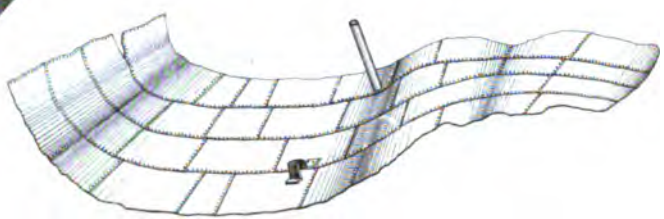


Fig. 8. *British Tube Boiler exploded from bad repair over fireplace. Length 26'0" Diam. 10'0" Deepfields 1865.*



(Proceedings Inst. M.E. 1866. Page 130.)

Fig. 9. *Two-Furnace Upright Boiler exploded from weakness of angle iron at crown of centre tube.*
Height 21'3" Diam. 9'0" Tube 4'8" diam.
Dudley 1862.

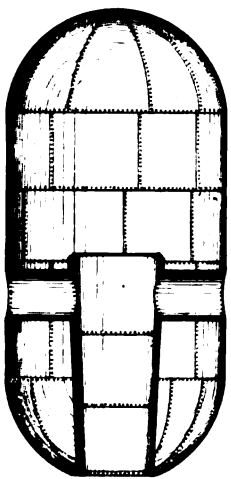


Fig. 11. *Cornish Boiler exploded from collapse of tube through want of strengthening rings.*
Length 35'0" Diam. 7'0" Tube 4'0" diam.
Burton 1865.

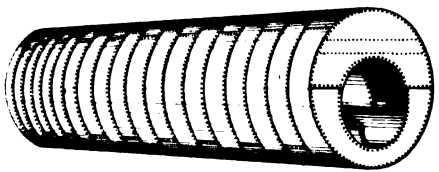


Fig. 12. *Internally Fired Upright Boiler exploded from weakness of fireplace.*
Height 20'0" Diam. 9'6"
Stoke-upon-Trent 1863.

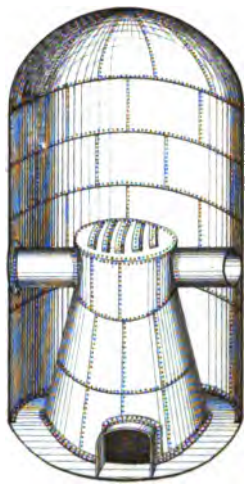


Fig. 10. *Angle-iron Joint at crown of centre tube.*

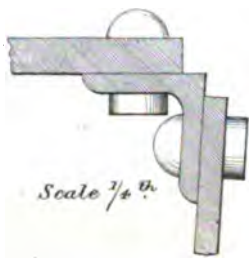
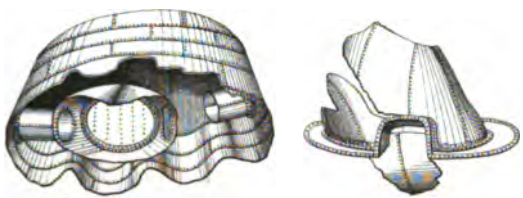


Fig. 13. *Appearance after explosion.*



(Proceedings Inst. M.E. 1866. Page 130.)

Fig. 14. *Steam Dome of Weak shape.*

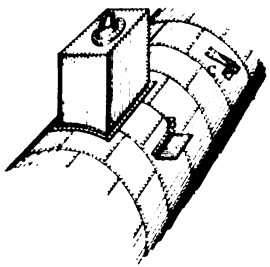


Fig 15. *Cornish Boiler exploded from corrosion at bottom.*
Length 30'0" Diam. 6'0" Tube 4'0" diam. at fire, 2'6" beyond.
Loughborough 1863.

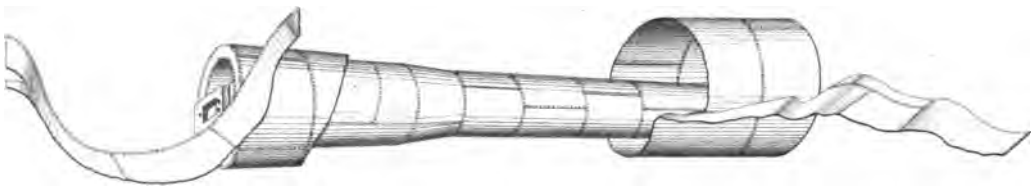
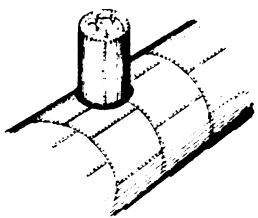


Fig. 16. *Explosion from too large manhole on steam dome 2'6" diam.*
Birmingham 1865.



Explosions from too large manhole.

Fig. 17. *Diam. 2'6" Manhole 1'6" × 1'1"*
Walsall 1865

Fig. 18.
Diam. 2'6"
Leicester 1866.

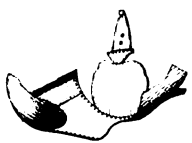
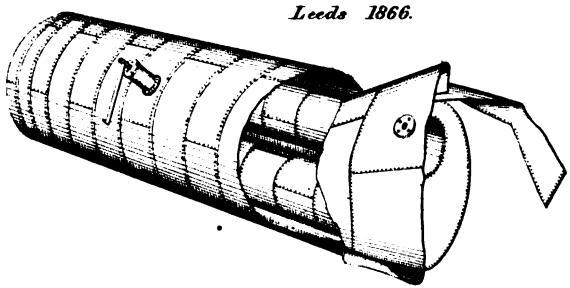


Fig. 19. *Lancashire Boiler*
exploded from corrosion at bottom.
Length 25'0" Diam. 7'0" Tubes 2'5" diam.
Leeds 1866.



(Proceedings Inst. M.E. 1866. Page 130.)

BOILER EXPLOSIONS.

Plate 47.

Fig. 20. *Three-Furnace Upright Boiler exploded by overheating. Height 24'0" Diam. 7'9" Birmingham 1865*

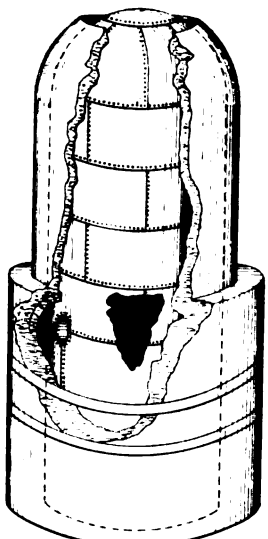


Fig. 21. *Four-Furnace Horizontal Boiler. Tube collapsed from overheating. Length 22'0" Diam 6'6" Kidderminster 1865.*

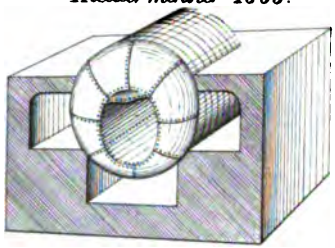


Fig. 22. *Plain Cylindrical Boiler exploded from corrosion all along bottom where resting on brickwork.*

Length 25'0" Diam. 5'0" Wigan. 1865.

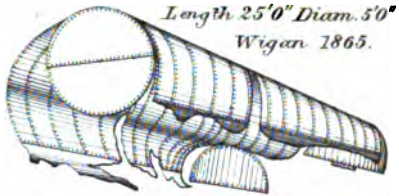


Fig. 23. *Lancashire Boiler exploded from corrosion of bottom. Length 18'0" Diam. 8'0" Leeds 1865.*

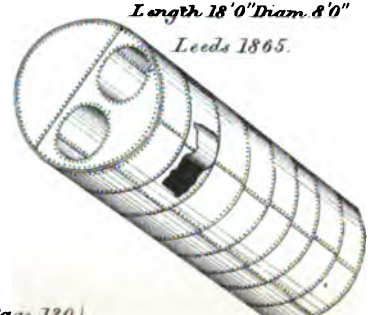


Fig. 24. *Oval Boiler set upon saddle wall, corroded into holes along bottom. Length 16'4" Height 6'6" Width 5'0"*

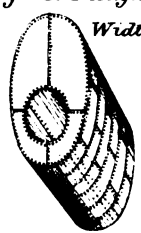
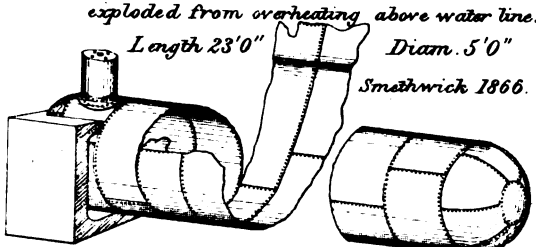


Fig. 25. *Plain Cylindrical Boiler exploded from corrosion of side. Length 21'0" Diam. 4'0" Sheffield 1865.*

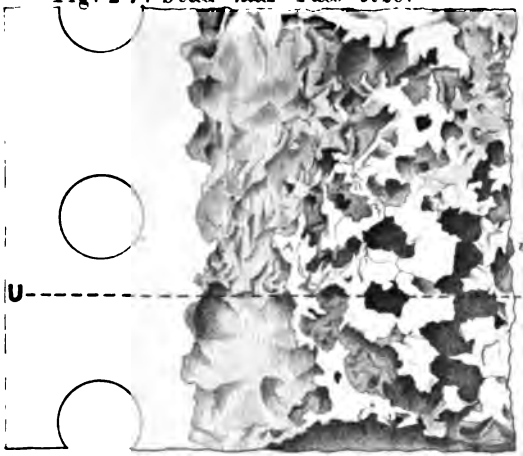
Fig. 26. *Plain Cylindrical Boiler exploded from overheating above water line. Length 23'0" Diam. 5'0" Smethwick 1866.*



(*Proceedings Inst. M.E. 1866. Page 130.*)

BOILER EXPLOSIONS.

Fig. 27. *Scale half full size.*



Internal Corrosion caused by bad feed water.

Corrosion in 8 years.

Corrosion in 10 years.

Fig. 28. *Scale* ½

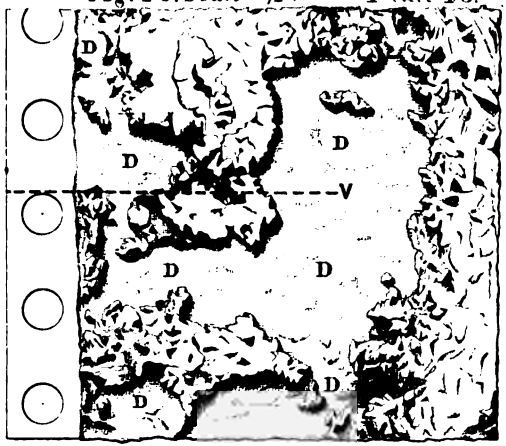


Fig. 29. *Full size section at* U U *(Fig. 27.)*

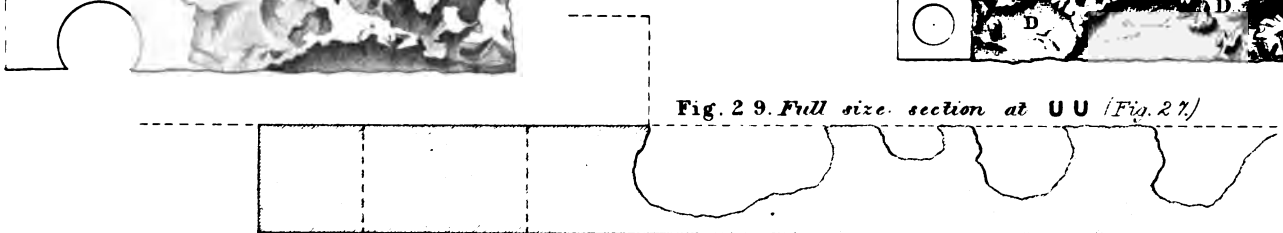
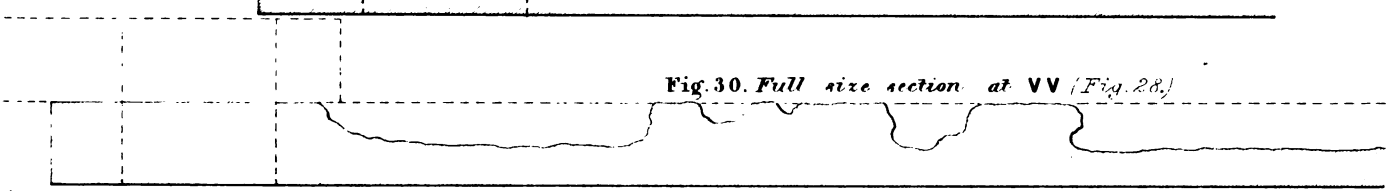


Fig. 30. *Full size section at* V V *(Fig. 28.)*



(Proceedings Inst. M.E. 1866. Page 130.)

Fig. 31. *External Corrosion from covering with Ashes.*

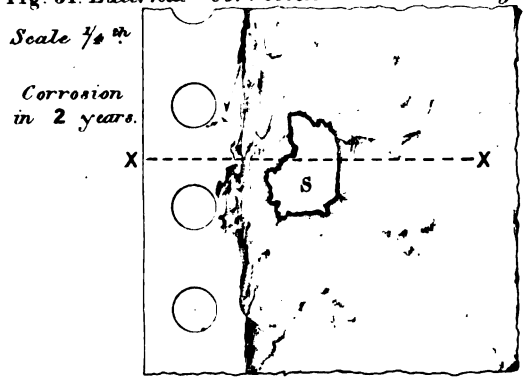
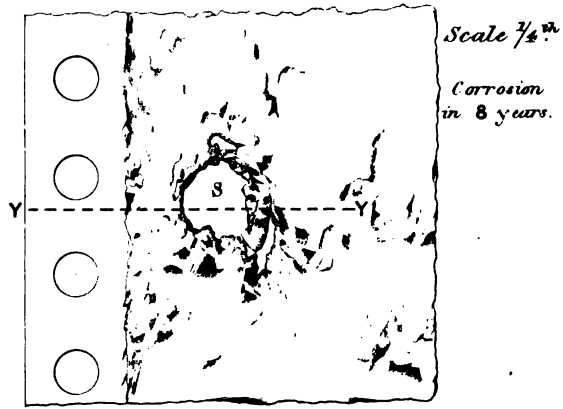


Fig. 32. *External Corrosion from covering with Sand.*



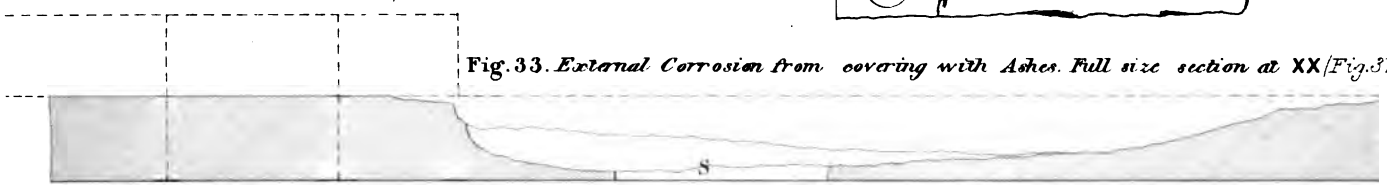


Fig. 33. *External Corrosion from covering with Ashes. Full size section at* XX *(Fig. 31.)*

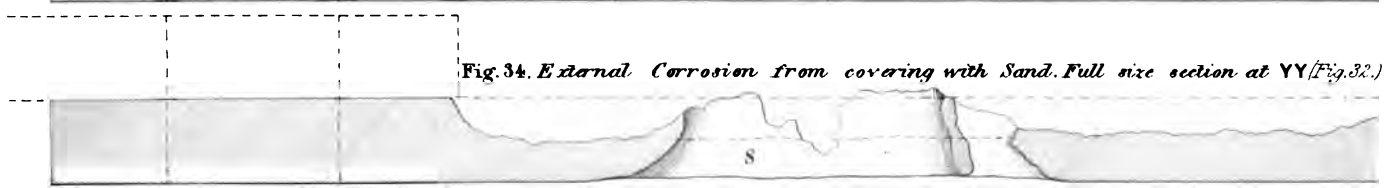


Fig. 34. *External Corrosion from covering with Sand. Full size section at* YY *(Fig. 32.)*

(Proceedings Inst. M.E. 1866. Page 130.)

BOILER EXPLOSIONS.

Fig. 35. *Section of Faulty Riveting and Caulking. Full size.*

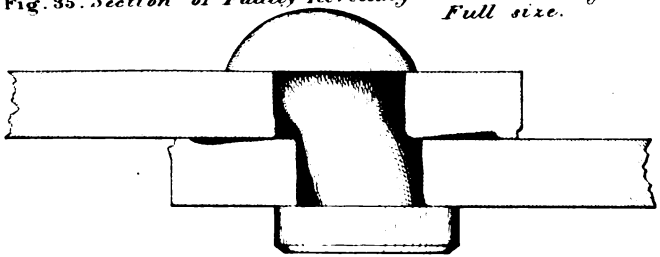


Fig. 36. *Lump of Scurf made up of chips from sides of boiler. Half full size.*

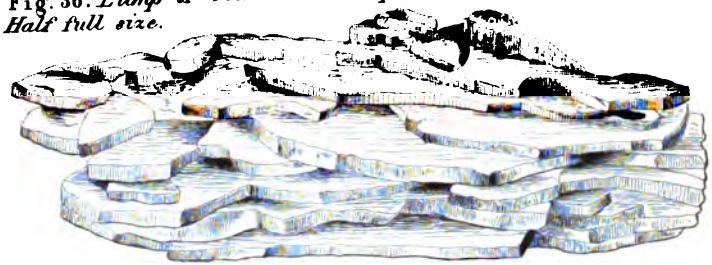


Fig. 37. *Explosion of "Pocket" caused by thick scurf over fire. Plain Cylindrical Boiler externally fired. Diam. 4'6" Dudley. 1864. Scale 1/8th*

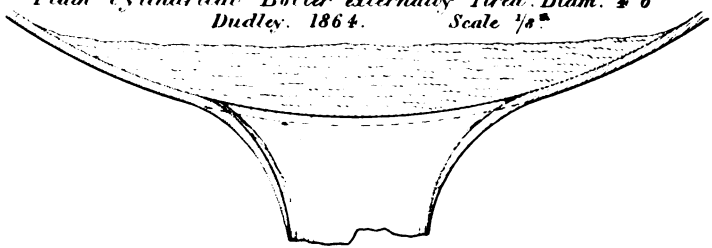
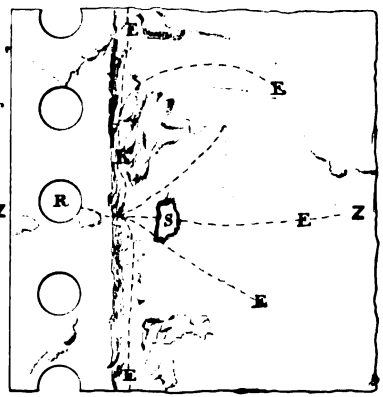
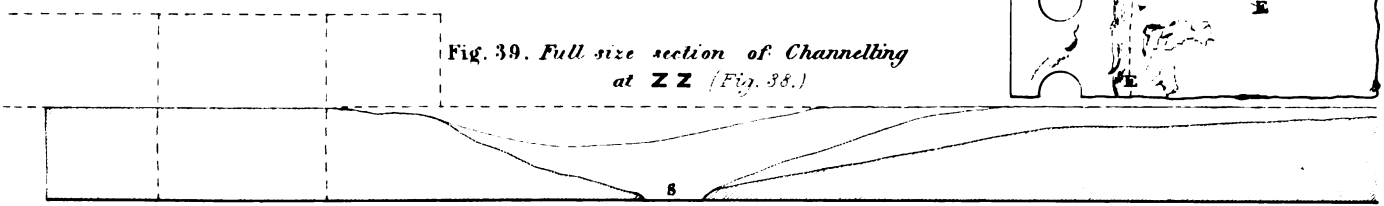


Fig. 38. *Channelling caused by Jet of steam and water from leaking rivet. Scale 1/8th*



Corrosion in 4 years.

Fig. 39. *Full size section of Channelling at* **Z Z** *(Fig. 38.)*



(Proceedings Inst. M.E. 1866. Page 130.)

Fig. 35. *Section of Faulty Riveting and Caulking. Full size.*

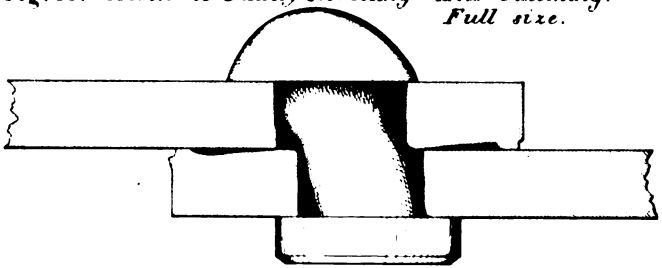


Fig. 36. *Lump of Scurf made up of chips from sides of boiler. Half full size.*

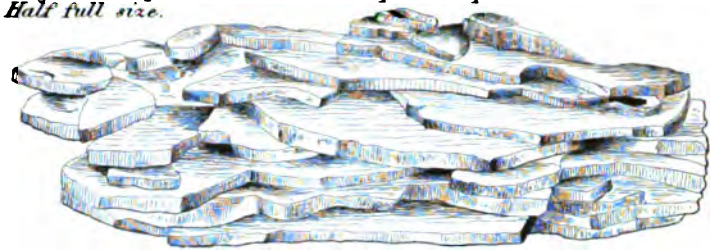


Fig. 37. *Explosion of "Pocket" caused by thick scurf over fire. Plain Cylindrical Boiler externally fired. Diam. 4'6" Dudley. 1864. Scale 1/8th.*

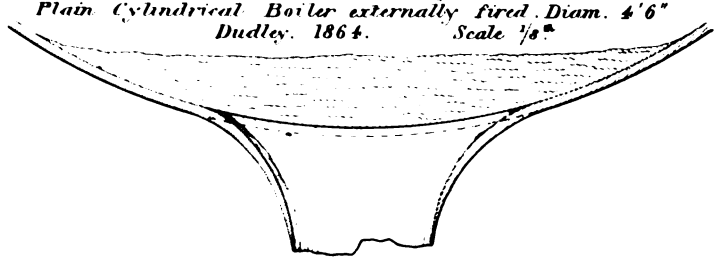
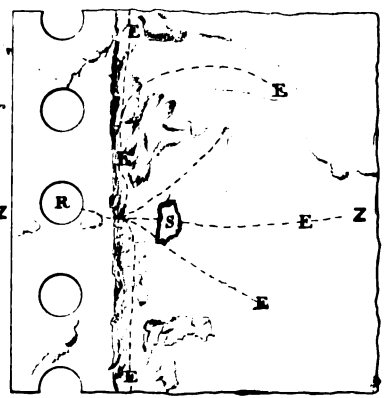


Fig. 38. *Channelling caused by Jet of steam and water from leaking rivet. Scale 1/8th.*



Corrosion in 4 years.

Fig. 39. *Full size section of Channelling at* **Z Z** *(Fig. 38.)*

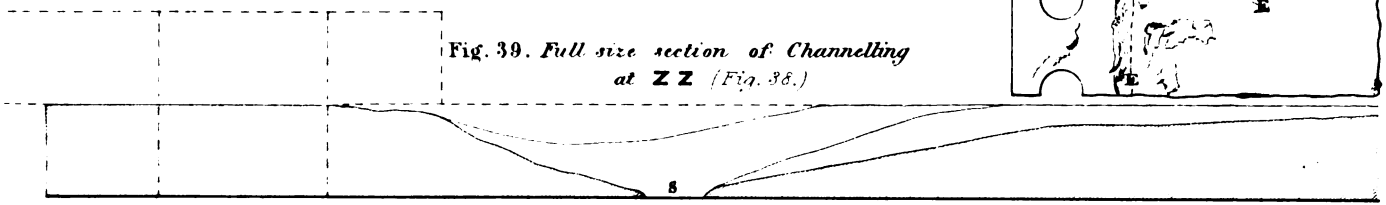


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Fig. 40.
Savery's Boiler.
Diam. 6'0"

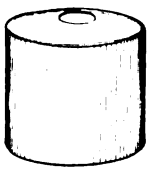

Fig. 41.
Tun Boiler.
Diam. 10'0"

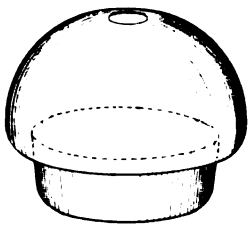

Fig. 42.
Flange Boiler.
Diam. 5'0"

Fig. 43.
Smeaton's Boiler.
Cast-iron.
Height 10'0" Diam. 6'0"

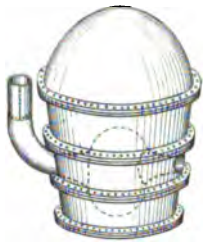

Fig. 44. *Watt's Boiler.*
Hooped wooden shell with copper tube.
Length 12'0" Diam. 5'0"

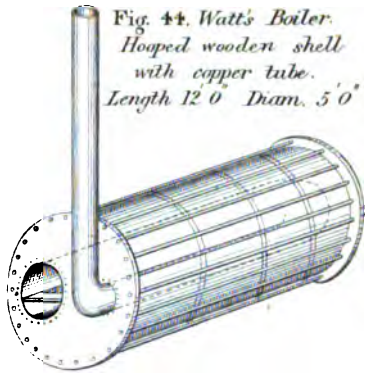

Fig. 45. *Brindley's Boiler.*
Stone chamber with copper tube.
Length 12'0" Diam. 5'0"

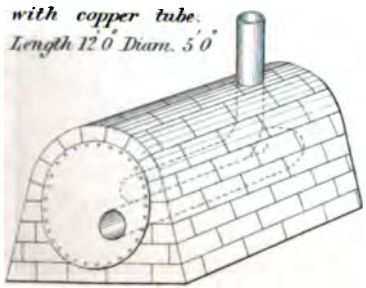

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Fig. 46. *Trevithick's Boiler.*
Cast-iron shell with wrought-iron tube.
Length 9'0" Diam. 4'6"

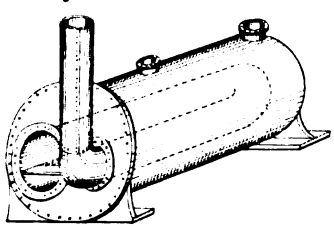

Fig. 47. *Woolf's Boiler. Cast-iron.*

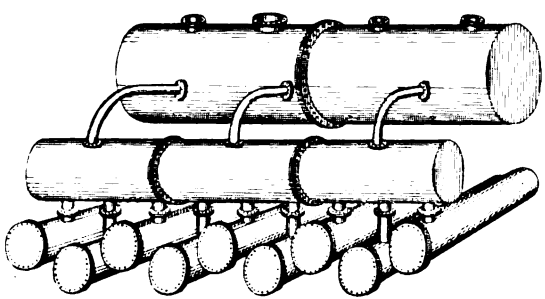

Fig. 48. *Wagon Boiler with flat sides. Length 22'0" Width 5'0" Height 7'0"*

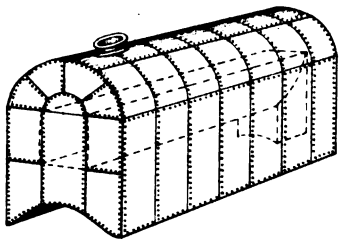

Fig. 49. *Wagon Boiler with concave sides. Length 22'0" Width 7'0" Height 7'0"*

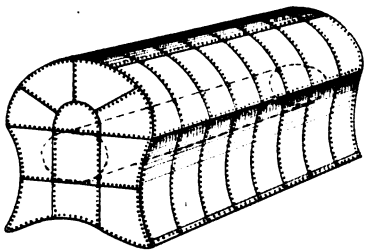

Fig. 52. *Spherical Boiler. Diam. 12'0"*

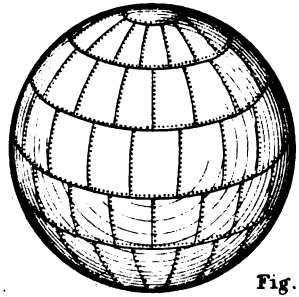

Fig. 53. *Boiler with spherical top and dished bottom. Diam. 12'0"*

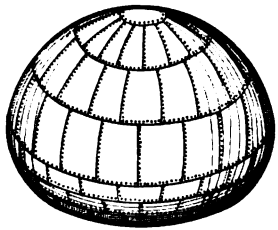

Fig. 50. *Wagon Boiler with rounded ends. Length 26'0" Height 8'0"*

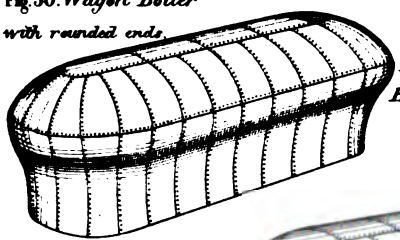

Fig. 51. *Wagon Boiler with convex bottom. Length 26'0" Height 9'0"*

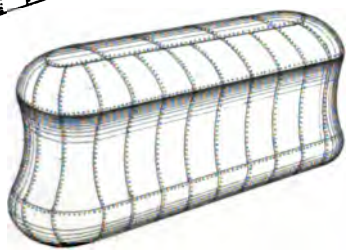

Fig. 54. *Haystack or Balloon Boiler with flat sides and bottom. Diam. 14'0"*

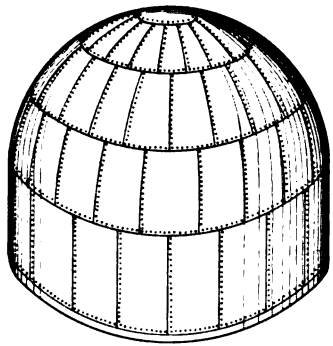

Fig. 55. *Haystack or Balloon Boiler with concave sides and bottom. Diam. 19'0"*

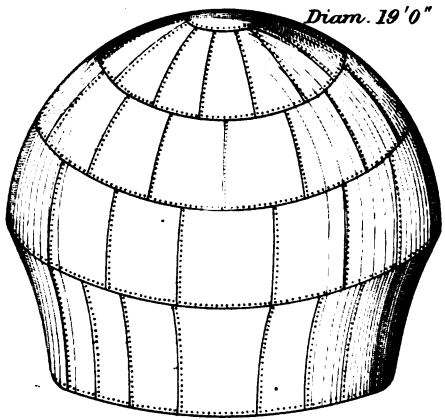

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Fig. 56. *Haystack or Balloon Boiler with internal fireplace and internal spiral flue. Diam. 12′ 0″*

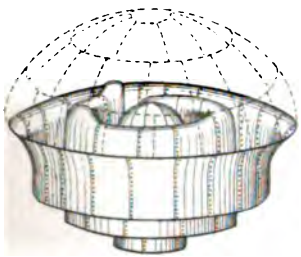

Fig. 57. *Plain Cylindrical Boiler with flat ends and straight seams. Length 20′ 0″ Diam. 6′ 0″*

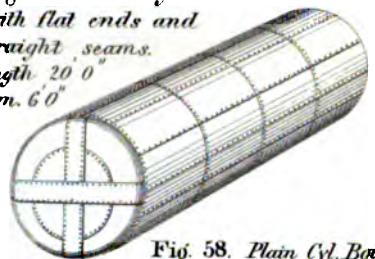

Fig. 58. *Plain Cyl. Boiler with spherical ends and crossed seams. Length 30′ 0″ Diam. 7′ 0″*

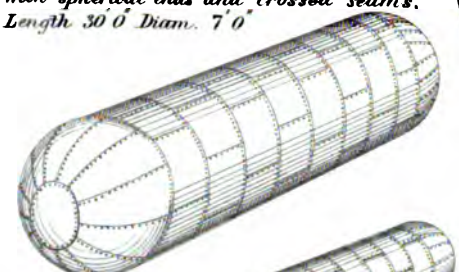

Fig. 59. *Annular Boiler. Diam. of circle 25′ 0″ outside. 15′ 0″ inside.*

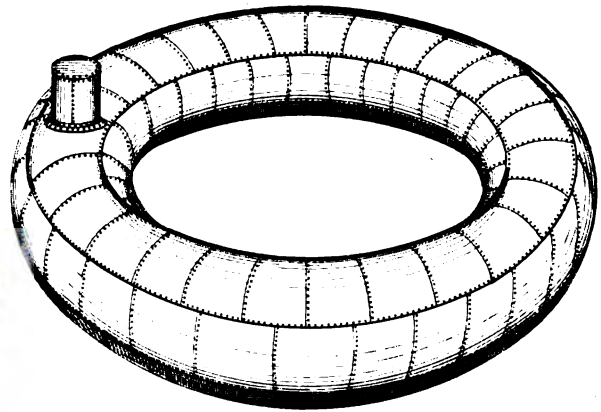

Fig. 60. *Retort Boiler. Retorts 1′ 5″ diam., 9′ 0″ length.*

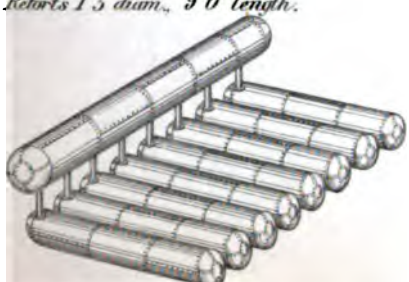

Fig. 61. *Elephant or French Boiler. Length 24′ 0″ Diams 4′ 0″ and 2′ 3″*

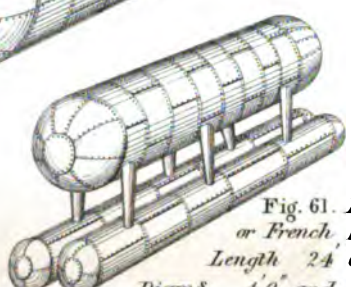

Fig. 62. *Lancashire Boiler with diagonal seams. Length 26′ 0″ Diam. 7′ 0″ Tubes 2′ 6″ diam.*

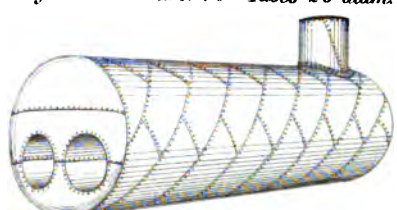

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Fig. 63. *Externally fired Boiler with internal tube.*
Length 28'0" Diam. 8'0"
Tube 3'0" diam.

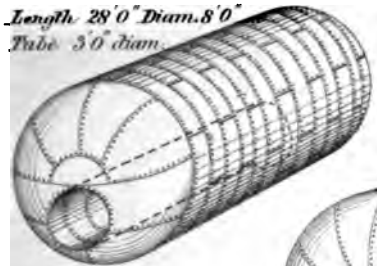

Fig. 64. *Externally fired Boiler with internal tubes.*
Length 28'0" Diam. 9'0"
Tubes 2'6" diam.

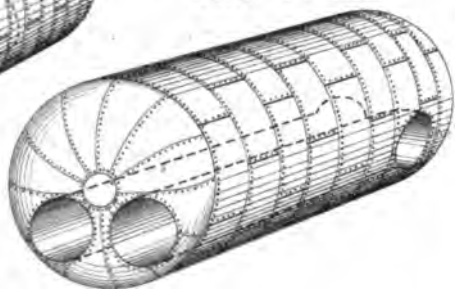

Fig. 65. *Externally fired Boiler with internal tube. Length 26'0" Diam. 7'6"*

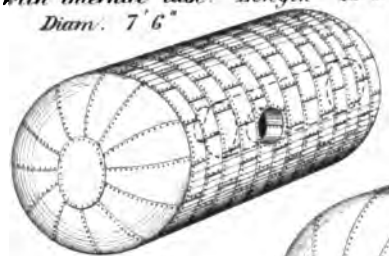

Fig. 66. *British-Tube Boiler, externally fired.*
Length 26'0" Diam. 10'0"
Tube 2'6" diam.

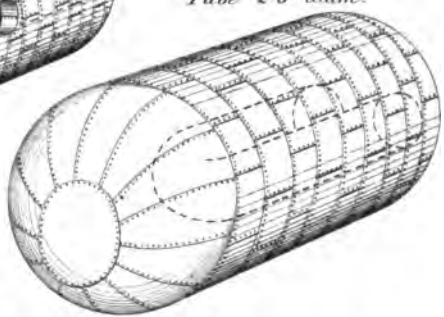

Fig. 67. *Cornish Boiler.*
Length 28'0" Diam. 7'0"
Tube 3'6" diam.

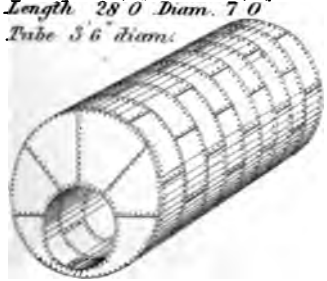

Fig. 68. *Lancashire Boiler.*
Length 30'0" Diam. 7'6"
Tubes 2'9" diam.

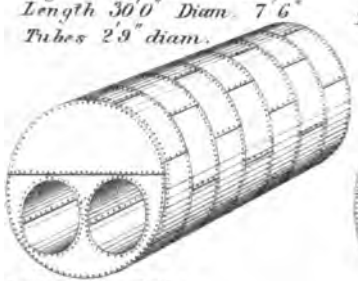

Fig. 69, *Breeches-Tube Boiler.*
Length 30'0" Diam. 8'0"
Tubes 2'8" diam.

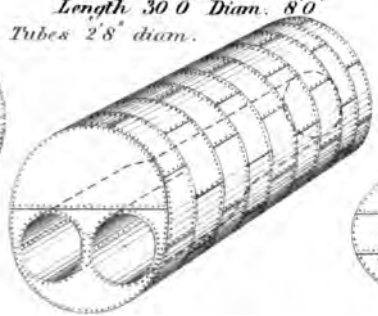

Fig. 70. *Oval Lancashire Boiler.*
Length 16'0" Width 10'0"
Height 6'6" Tubes 3'0" diam.

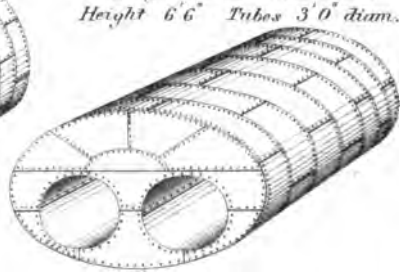

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Fig. 71. *Elbow Boiler.*
Length 20' 0" Diam. 4'6" Tube 1'3" diam.

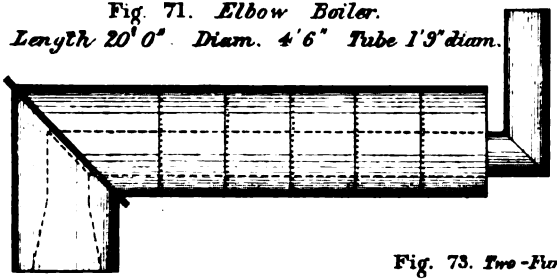

Fig. 72. *Butterley Boiler.*
Length 26'0" Diam. 9'0"
Fireplace 8'6" length. Tube 3'6" diam.

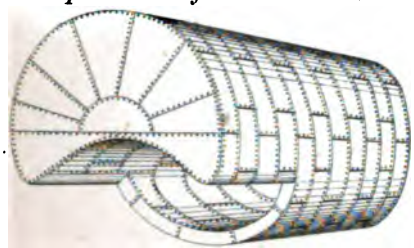

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Fig. 73. *Two-Furnace Upright Boiler.*
Height 16'6" Diam. 7'0"

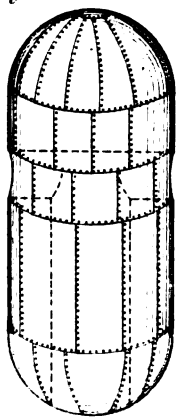


Fig. 74. *Four-Furnace Upright Boiler.*
Height 28'0" Diam. 10'0"

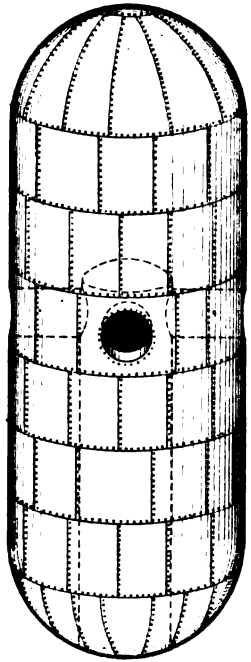


Fig. 75. *Chimney Boiler.*
Height 26'0" Diam. 5'6"
Tube 3'0" diam.

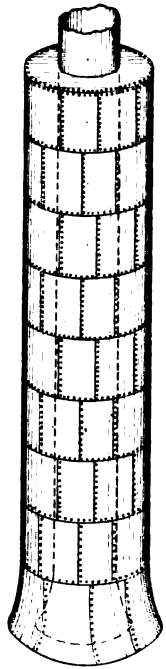
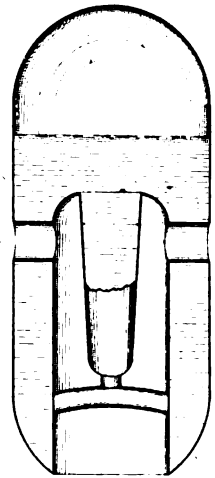


Fig. 76. *Internally fired Upright Boiler.*
Height 20'0" Diam. 9'0"



IRON COLUMNS OF COTTON MILL.

Plate 56.

Fig. 1. *Longitudinal Section of Cotton Mill.*

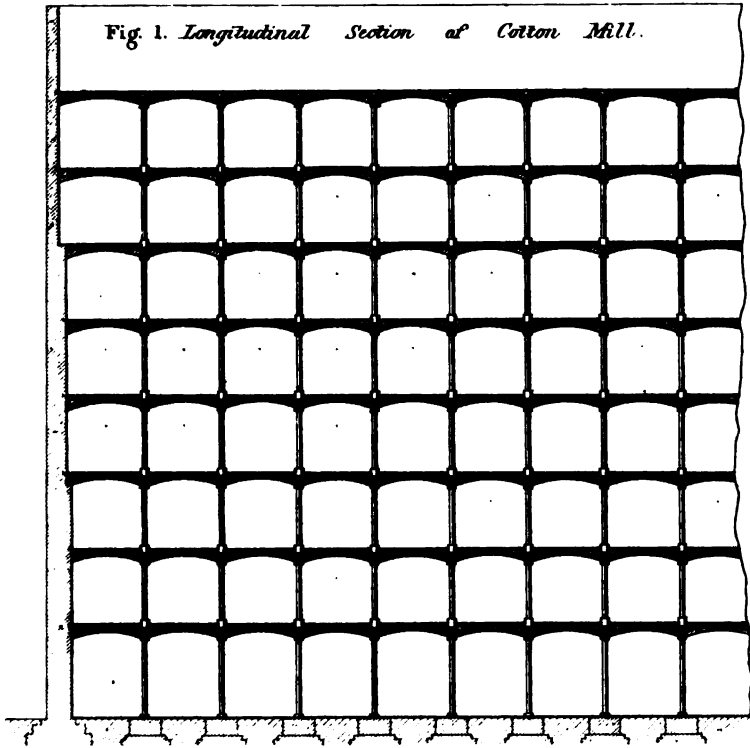
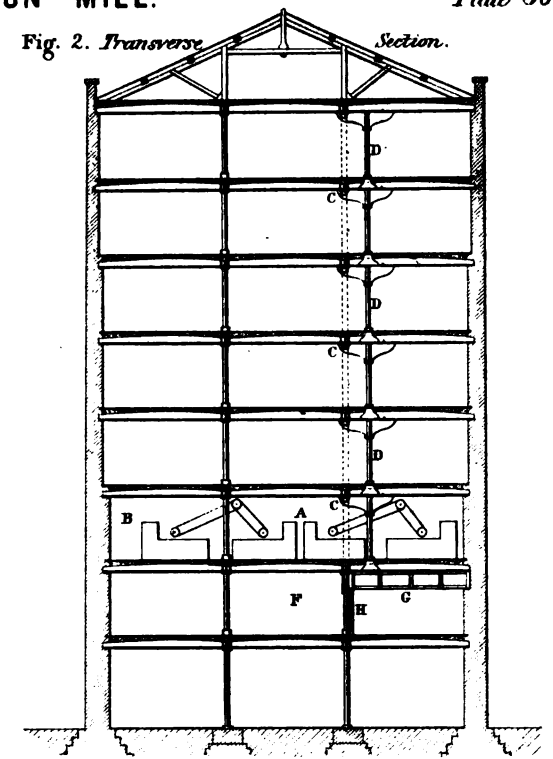


Fig. 2. *Transverse Section.*

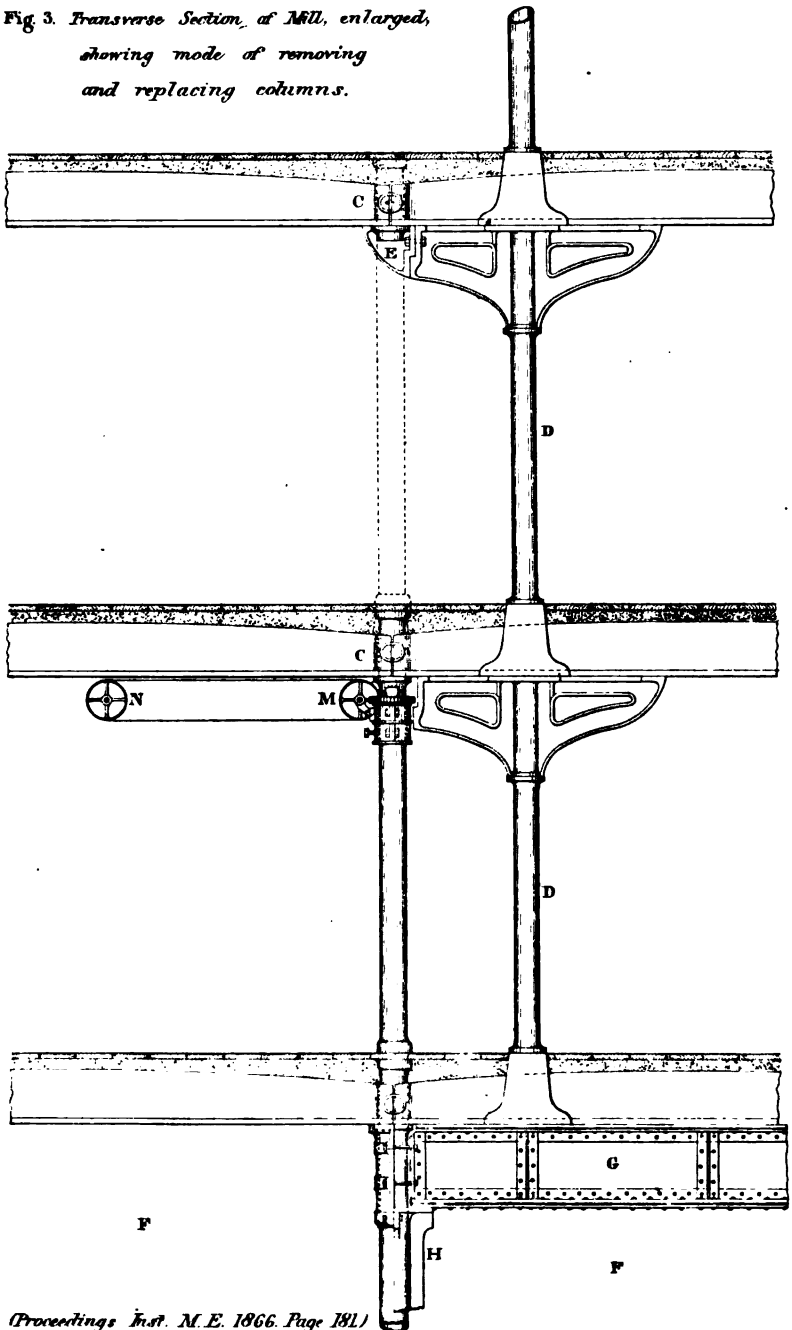


(Proceedings Inst. M.E. 1866. Page 181.) Scale $\frac{1}{300}$th

10 5 0 10 20 30 40 50 60 70 80 Feet.

IRON COLUMNS OF COTTON MILL. *Plate 57.*

Fig. 3. *Transverse Section of Mill, enlarged, showing mode of removing and replacing columns.*



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Scale 1/50 th 0 1 2 3 4 5 6 7 8 9 *in Feet.*

Fig. 4. *Elevation of Apparatus for cutting away Columns.*

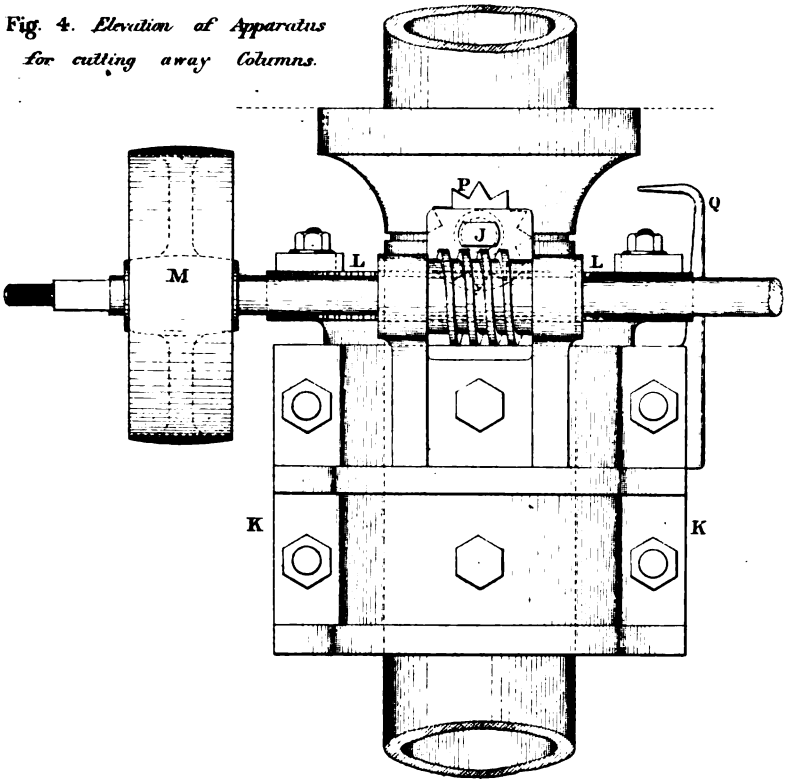
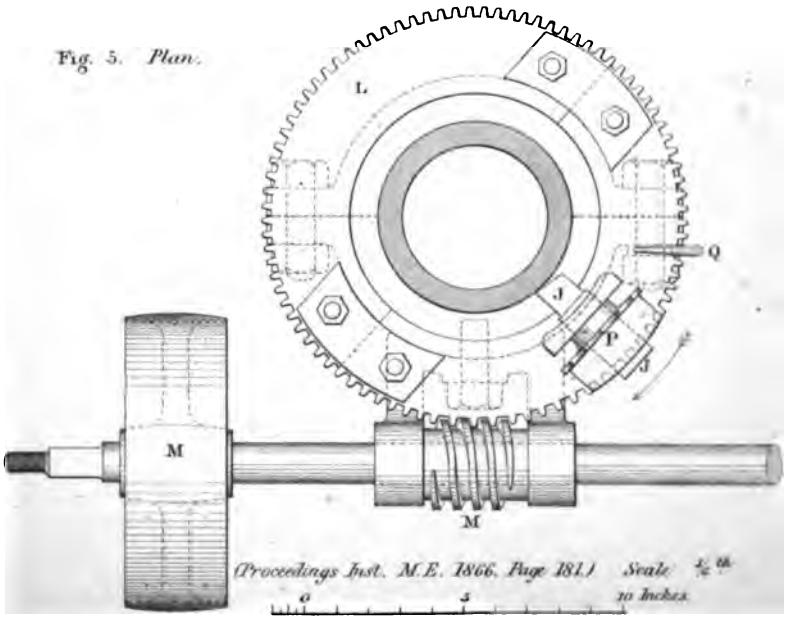


Fig. 5. *Plan.*



(Proceedings Inst. M.E. 1866. Page 181.) Scale $\frac{1}{2}$ths

MANUFACTURE OF STEEL TYRES. *Plate 59.*

Fig. 1. *Vertical Section of Casting Mould.*

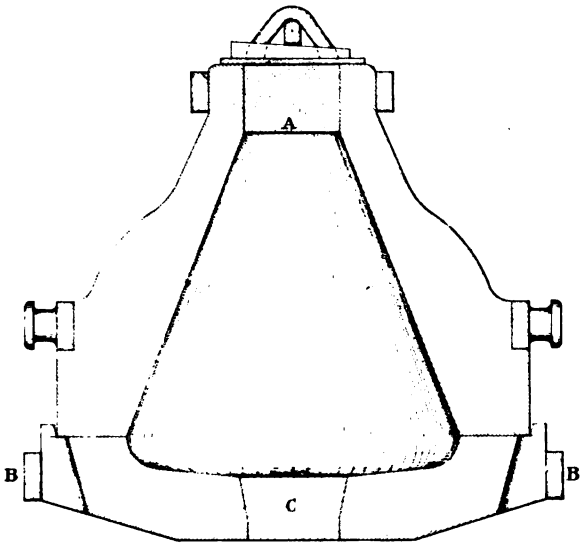
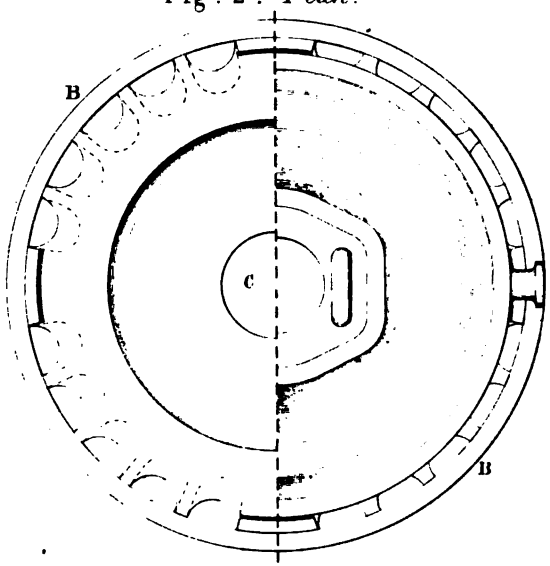


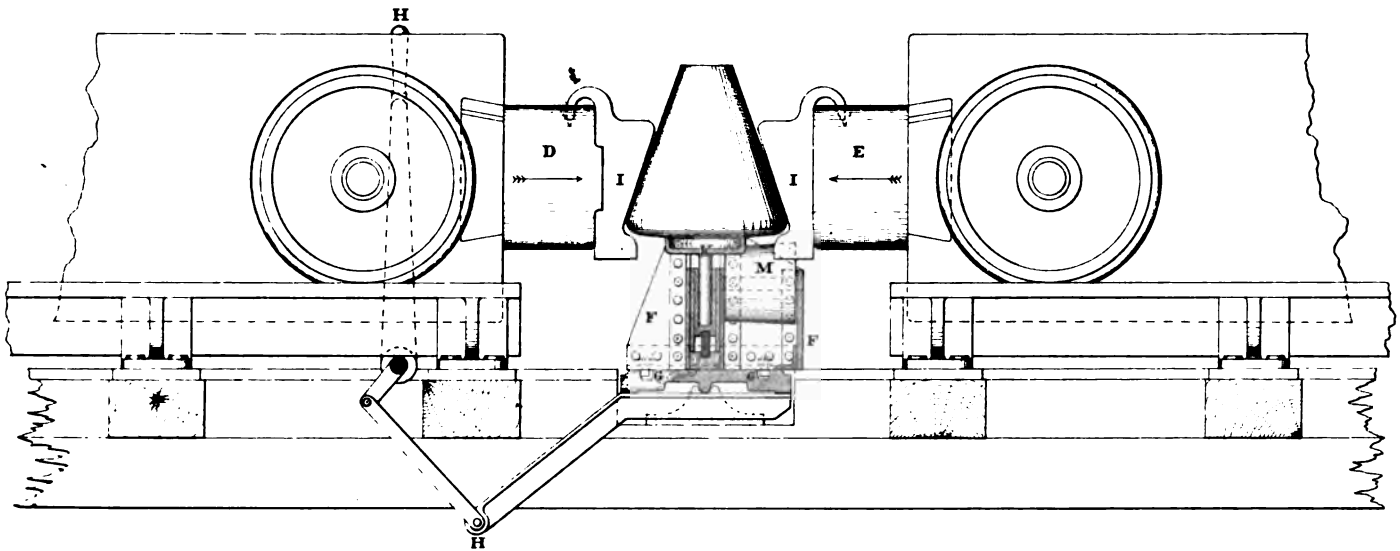
Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale* 1/12 th.

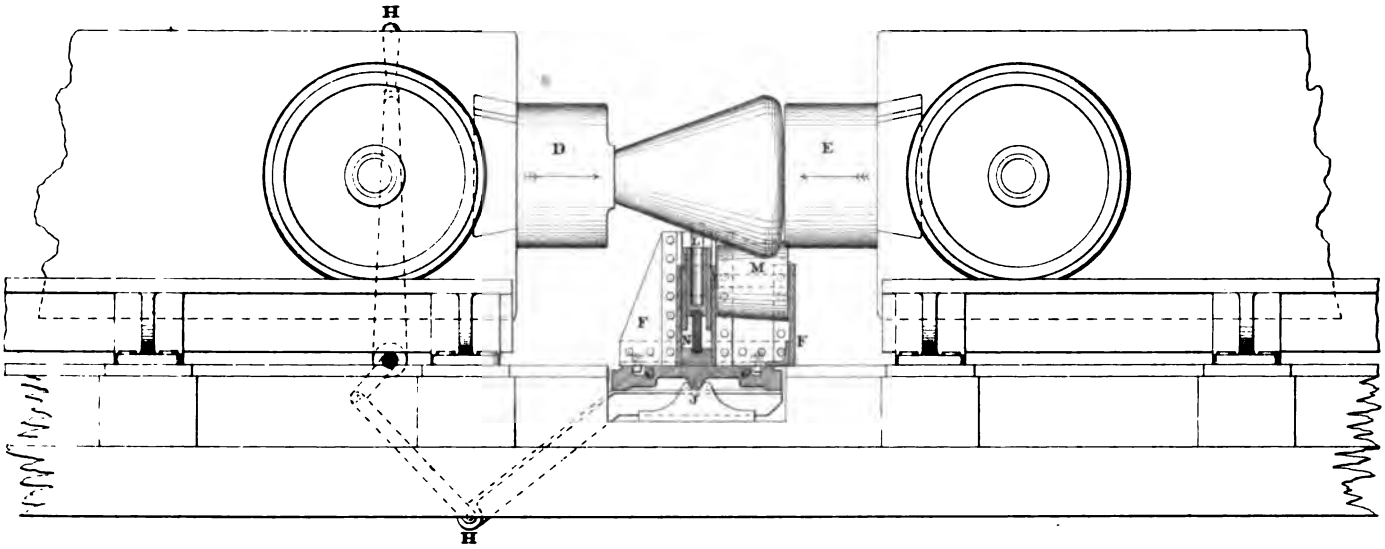
10 5 0 10 20 30 Inches.

Fig. 3. *Side Elevation of Horizontal Duplex Hammer, hammering Bloom laterally.*



(Proceedings Inst. M.E. 1866. Page 186.) *Scale 1/24th* Ins. 12 6 0 1 2 3 4 5 Feet.

Fig. 4. *Side Elevation of Horizontal Duplex Hammer, hammering Bloom endways.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale* 1/24th Ins. 12 6 0 1 2 3 4 5 Feet.

Fig. 5. *Transverse Section of Horizontal Duplex Hammer, hammering Bloom laterally.*

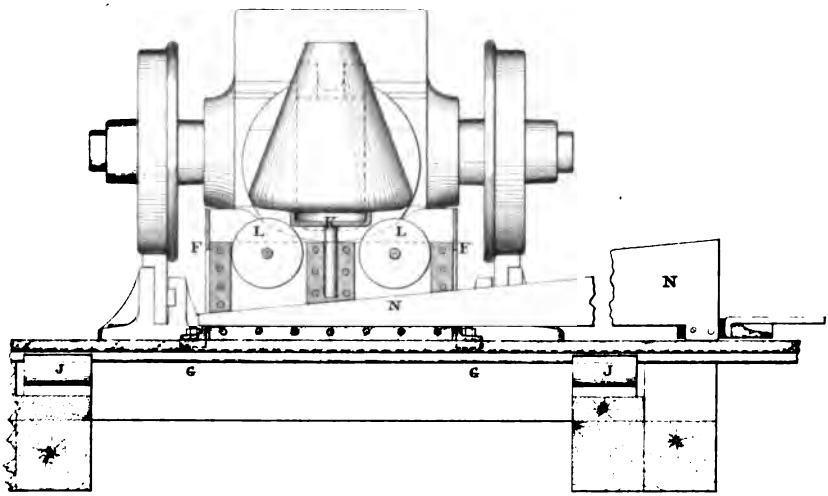
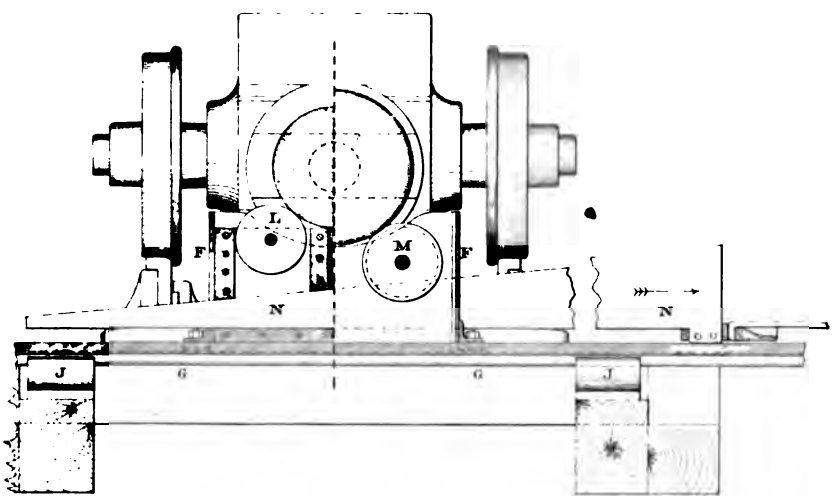


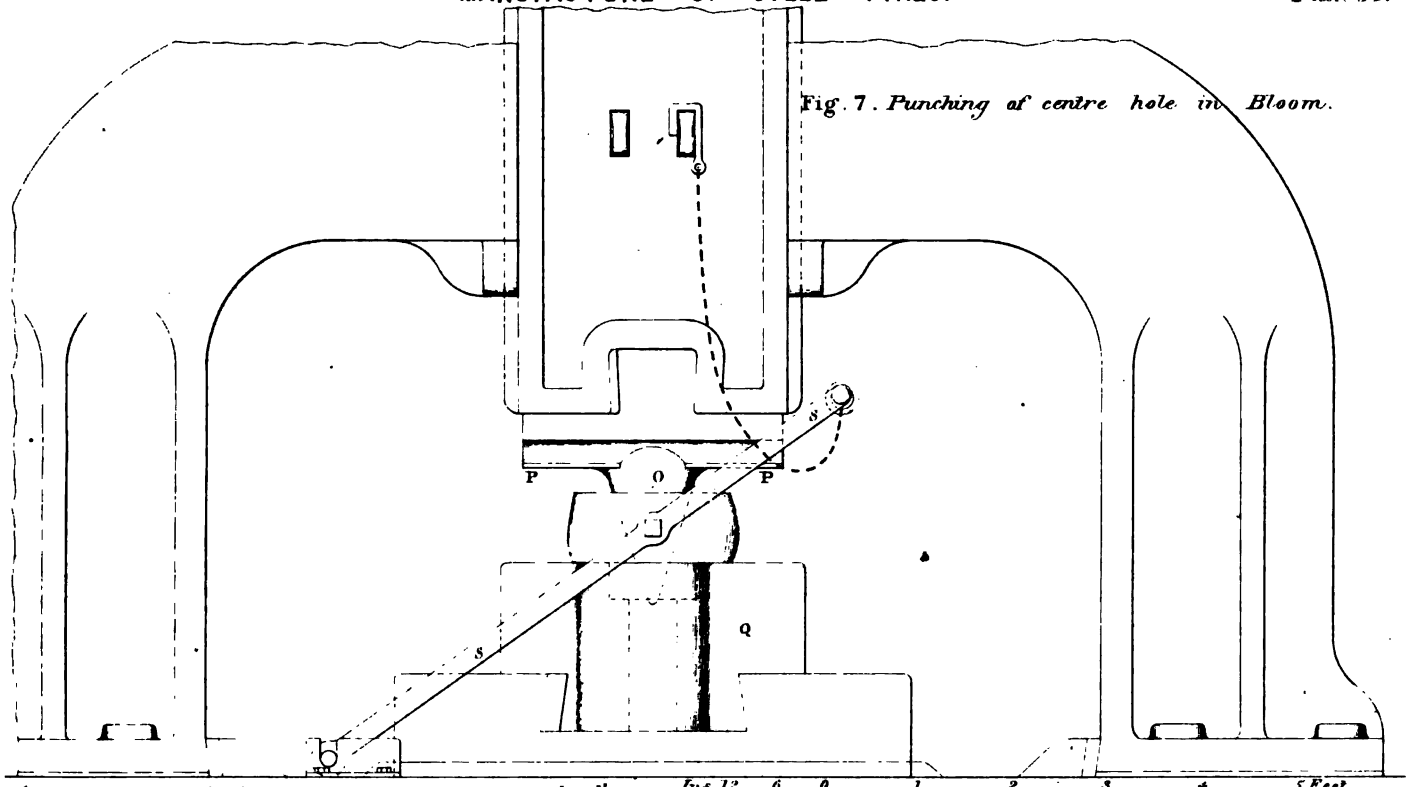
Fig. 6. *Transverse Section of Horizontal Duplex Hammer, hammering Bloom endways.*



(Proceedings Inst. M.E. 1866. Page 186.) *Scale* 1/24th

Ins. 12 6 0 1 2 3 4 5 Feet.

Fig. 7. *Punching of centre hole in Bloom.*



(Proceedings Inst. M.E. 1866. Page 186) *Scale 1/24th*

MANUFACTURE OF STEEL TYRES.

Punching of centre hole in Bloom.

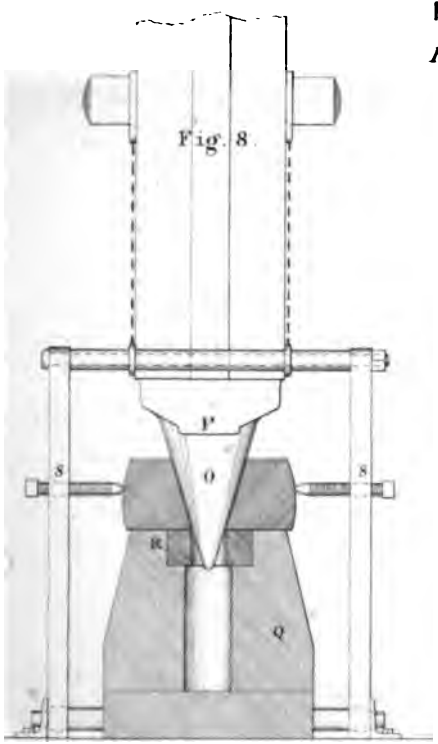


Fig. 8.

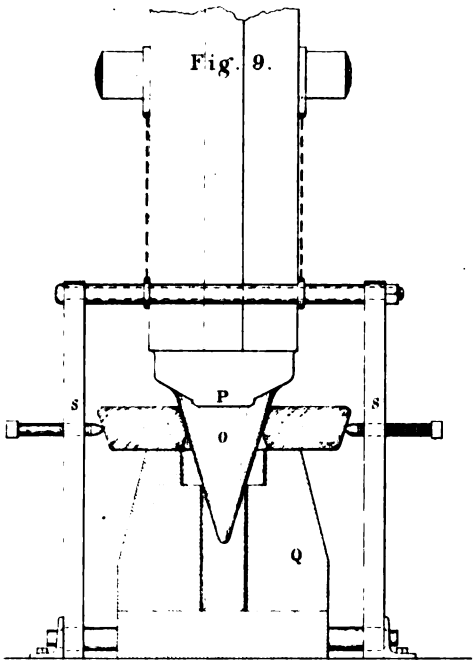
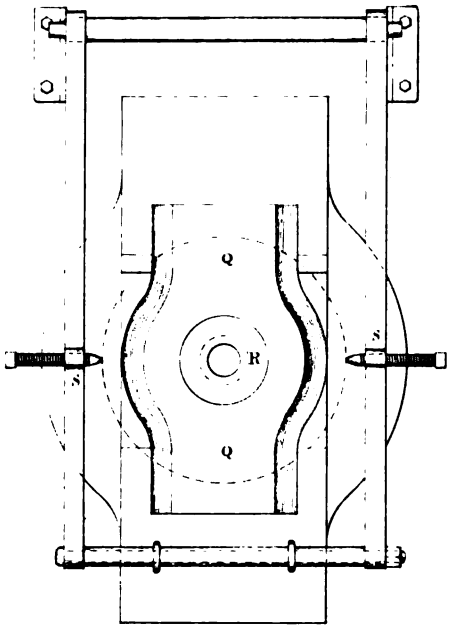


Fig. 9.

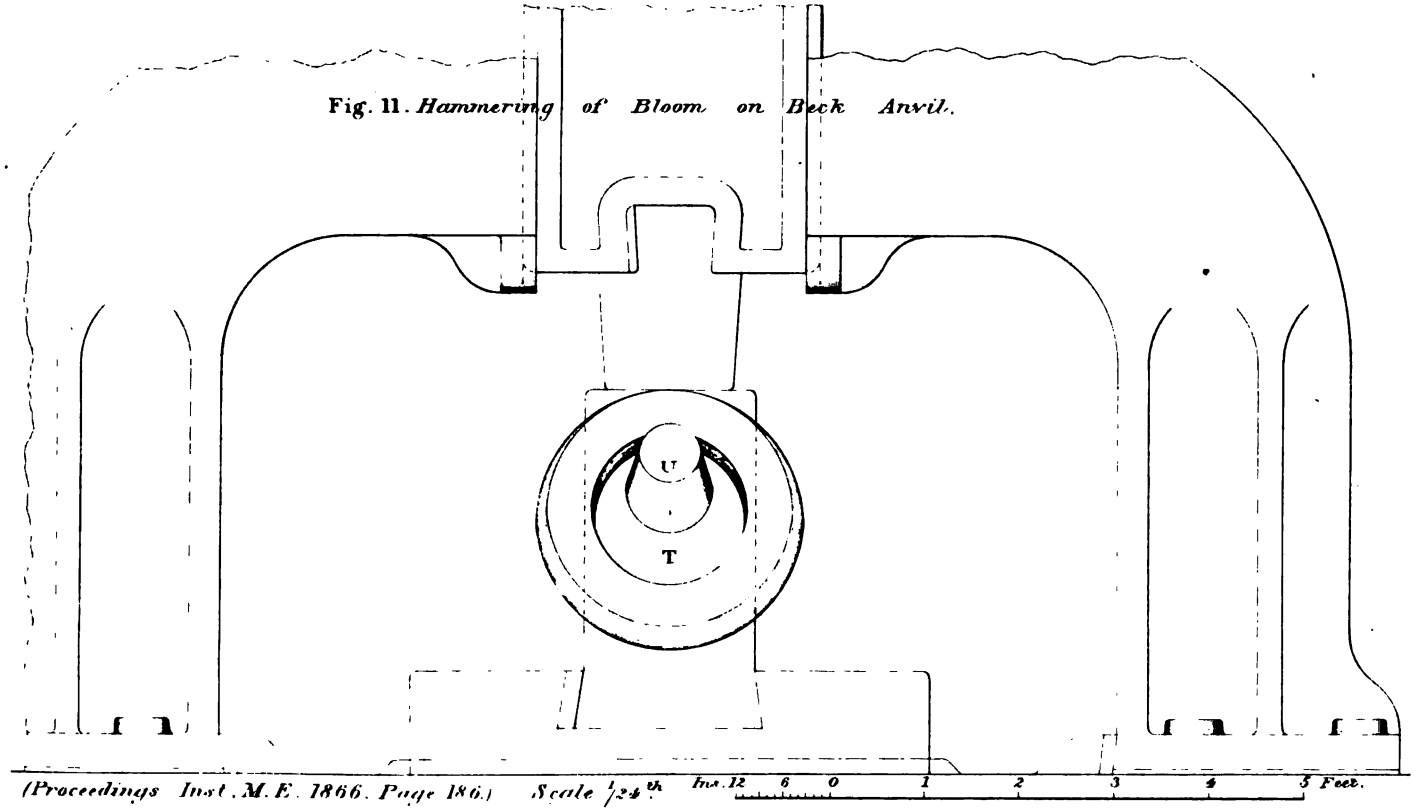
Fig. 10. *Plan of Anvil Block and Swing Frame.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale* 1/24th

Ins. 12 6 0 1 2 3 4 5 Feet.

Fig. 11. *Hammering of Bloom on Beck Anvil.*



(Proceedings Inst. M.E. 1866. Page 186.) *Scale 1/24th*

MANUFACTURE OF STEEL TYRES.

Plate 66.

Hammering of Bloom on Beck Anvil.

Fig.12.

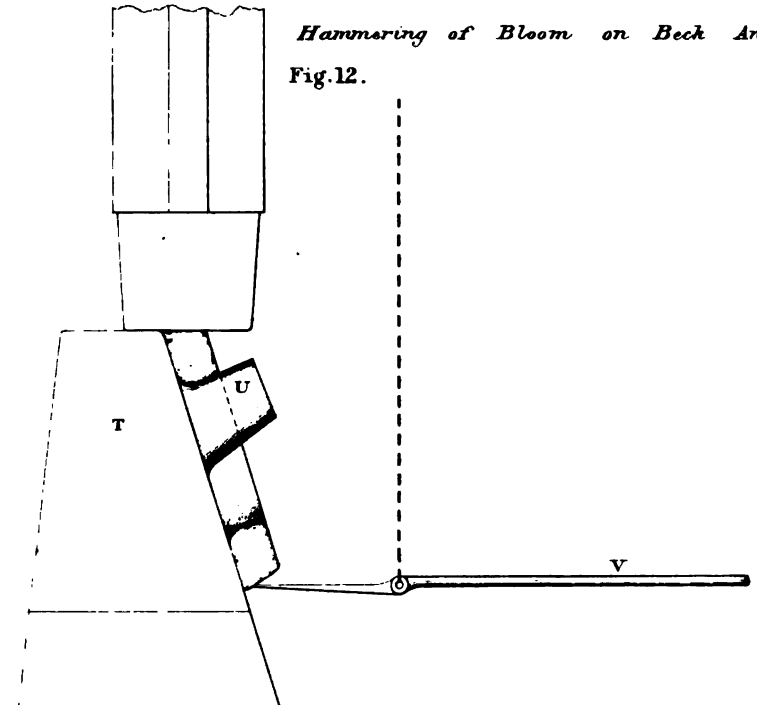
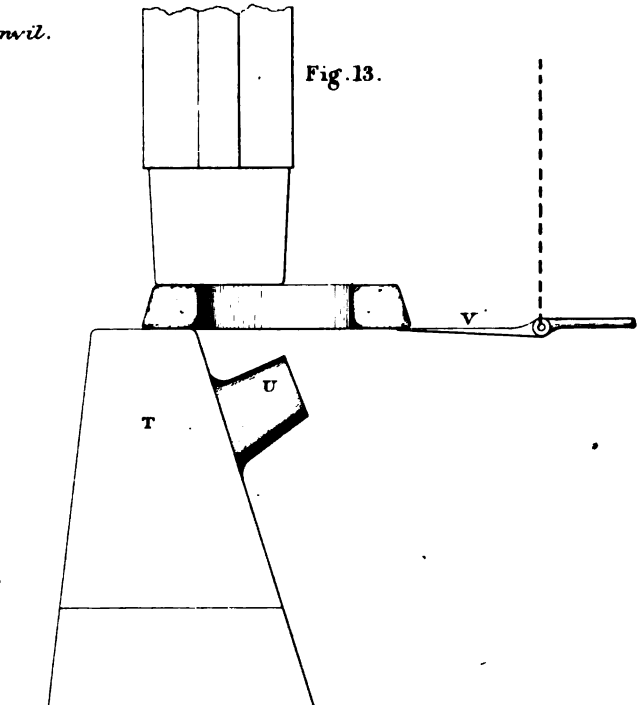
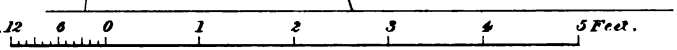


Fig.13.



(Proceedings Inst. M.E. 1866. Page 186.) *Scale 1/24th*



MANUFACTURE OF STEEL TYRES.

Fig. 14. *Steel Ingot from Casting Mould.*

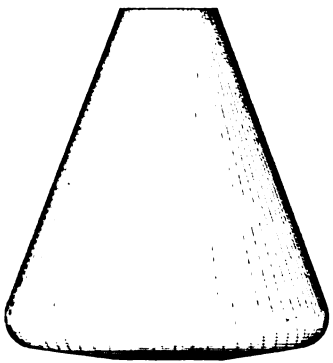


Fig. 15. *Hammered Bloom from Horizontal Duplex Hammer.*

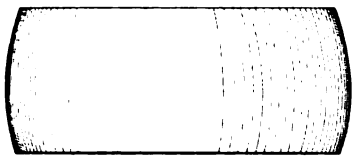


Fig. 16. *Centre hole punched.*

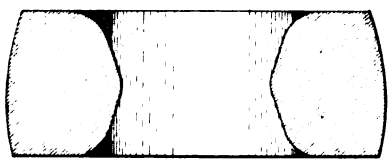


Fig. 17. *After working under Punching Hammer.*

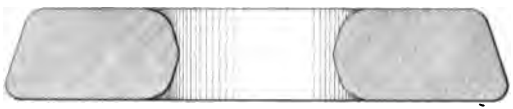


Fig. 18. *After hammering on Beck Anvil.*

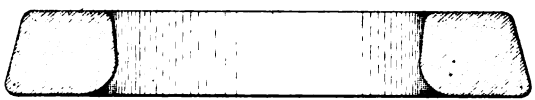
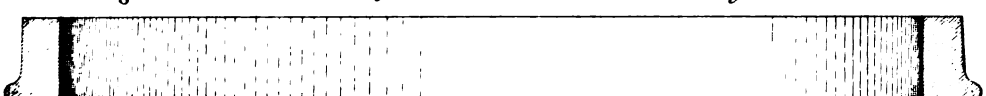


Fig. 19. *Finished Tyre from Circular Rolling Mill.*



(Proceedings Inst. M.E. 1866. Page 186.) *Scale* $\frac{1}{12}$ *th*

Fig. 1. *Arkwright's Spinning Machine. 1769.*
Scale 1/10th

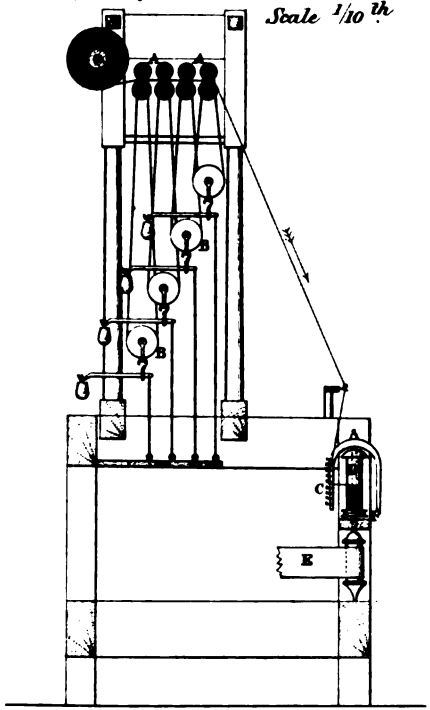
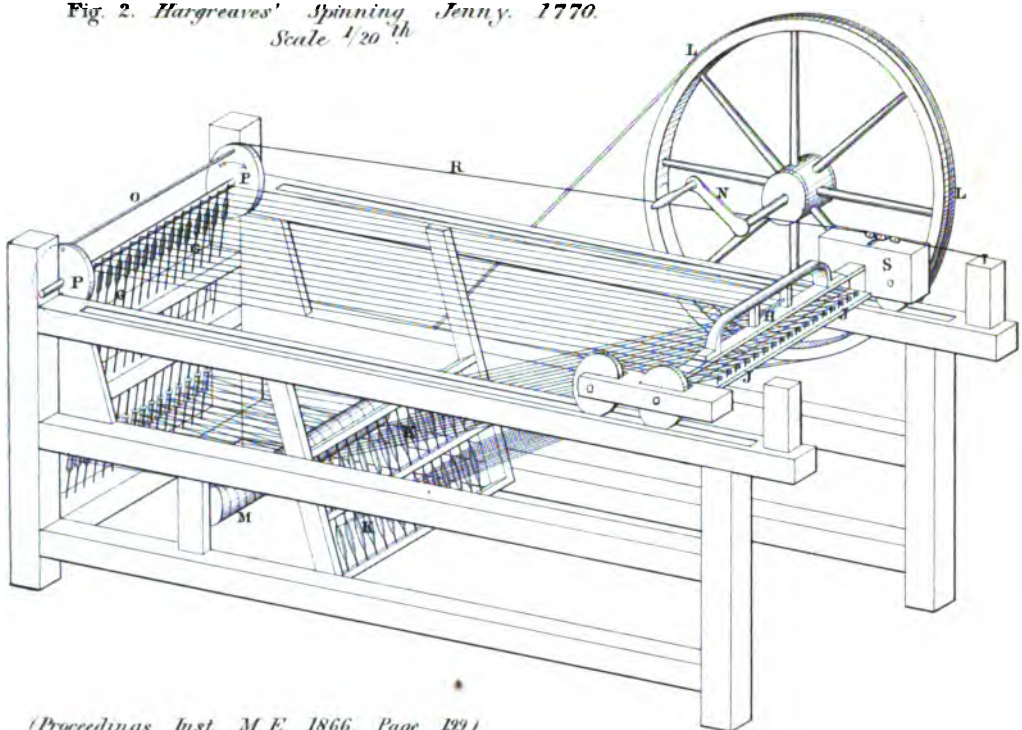


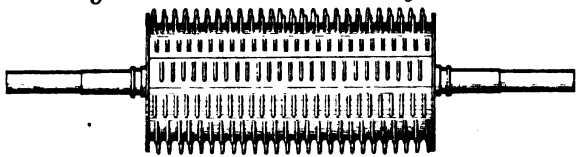
Fig. 2. *Hargreaves' Spinning Jenny. 1770.*
Scale 1/20th

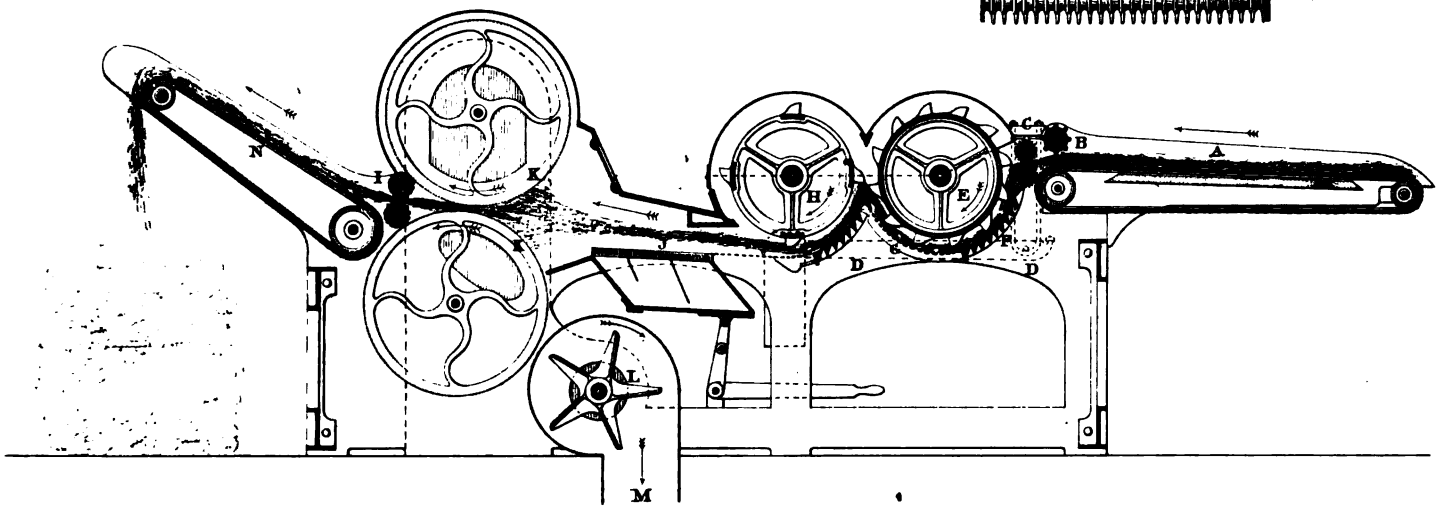


(Proceedings Inst. M.E. 1866. Page 129.)

Fig. 3. *Cotton Opener.* 1866.

Fig. 4. *Plan of Picker Cylinder.*





(Proceedings Inst. M.E. 1866. Page 199.)

Fig. 6. *Plan of Beater.*

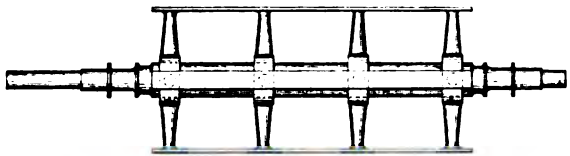
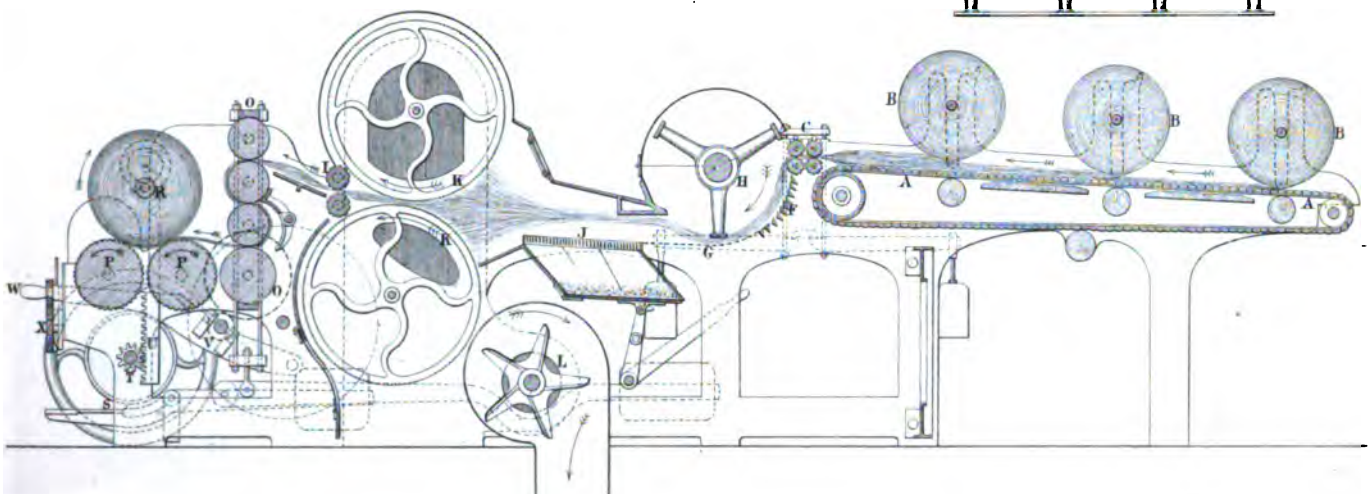


Fig. 5. *Single Scutcher and Lap Machine. 1866.*



Scale 1/24 th Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M. E. 1866. Page 199.)

COTTON MACHINERY.

Fig. 8. *Roller and Clearer.*

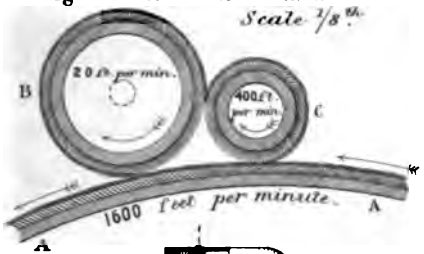


Fig. 7. *Roller and Clearer Carding Machine.* 1866.

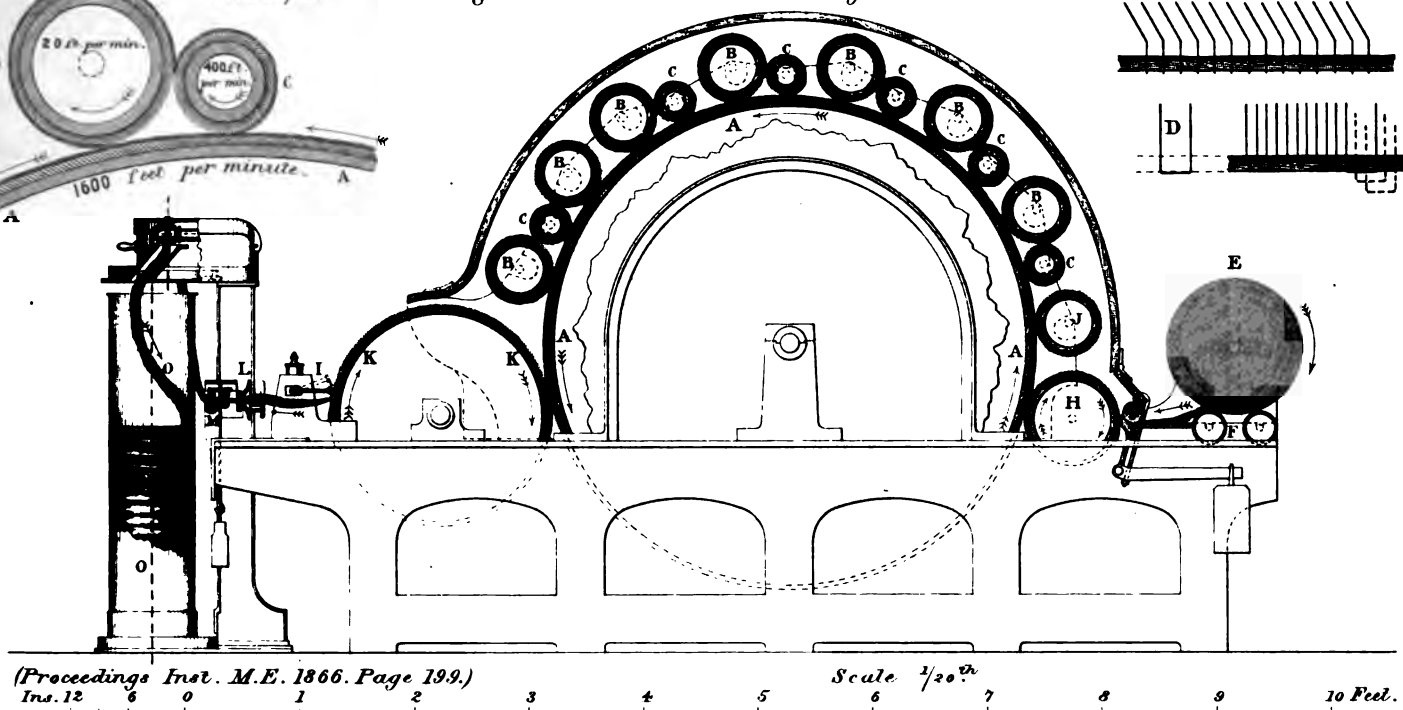


Fig. 9. *Card. Full size.*

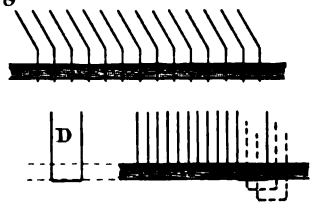
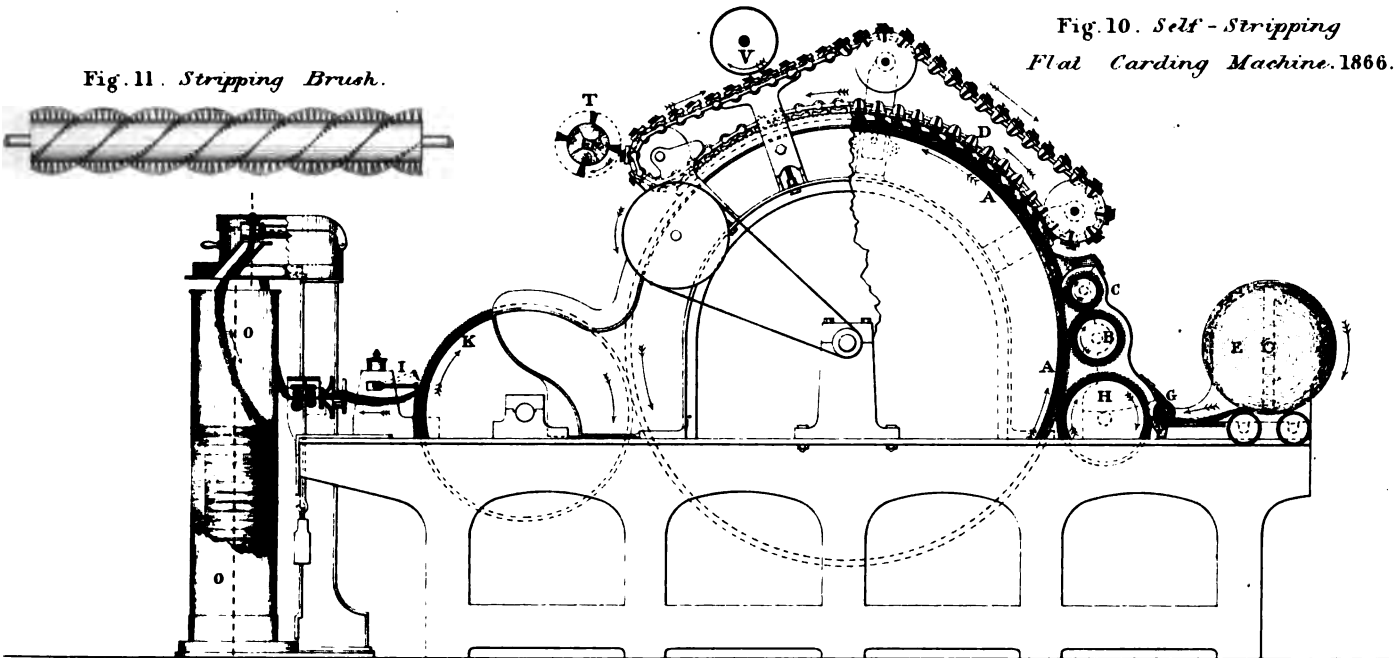


Fig. 11. *Stripping Brush.*

Fig. 10. *Self-Stripping Flat Carding Machine.* 1866.



(Proceedings Inst. M.E. 1866. Page 199.)

Scale 1/20th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

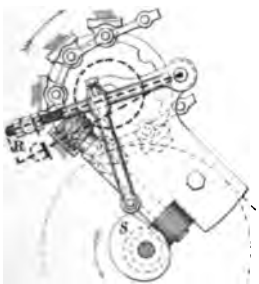
Fig. 12. *Self-Stripping Flat Carding Machine.*

Enlarged View of Cards.

Scale 1/10th

Fig. 13.

Vibrating Comb for stripping the Cards.



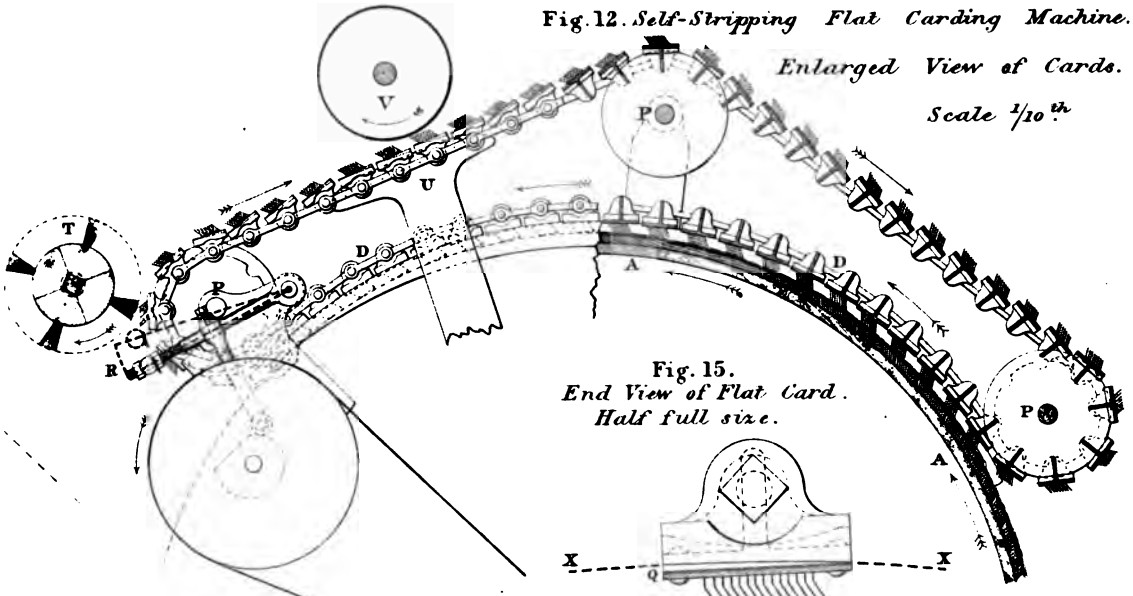
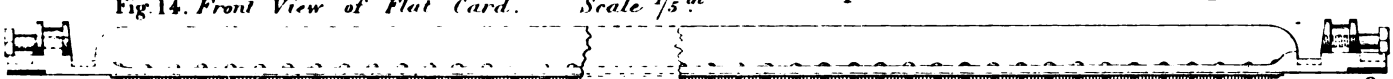


Fig. 15.
End View of Flat Card.
Half full size.

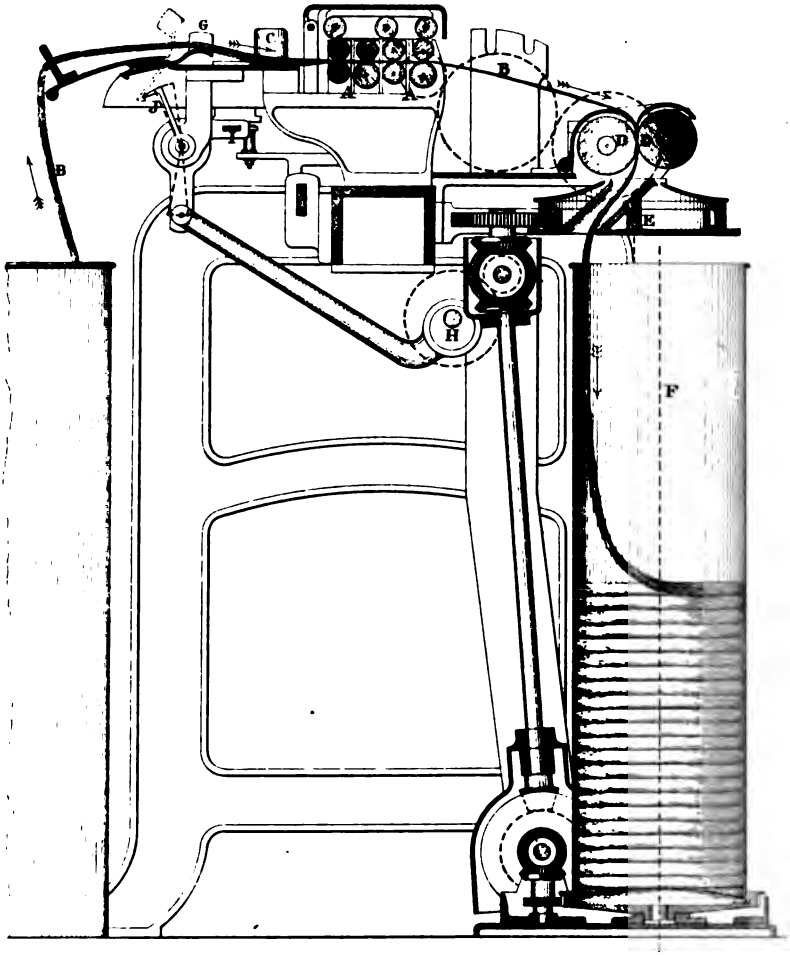
Fig. 14. *Front View of Flat Card.* *Scale 1/5th*



(Proceedings Inst. M. E. 1866. Page 199.)

Scale 1/10th

Fig. 16. *Drawing Frame. 1866.*

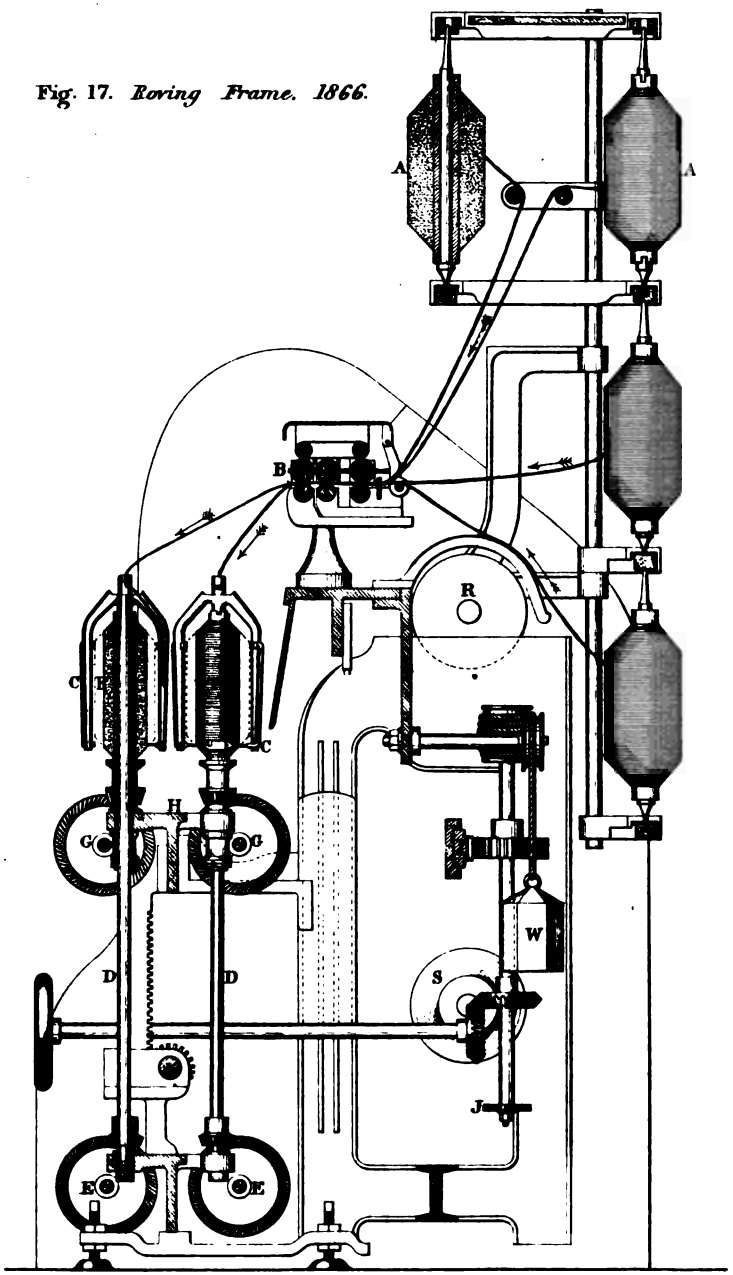


Scale 1/10 *th*

0 5 10 15 20 25 30 Inches.

(Proceedings Inst M. E. 1866. Page 122.)

Fig. 17. *Roving Frame. 1866.*

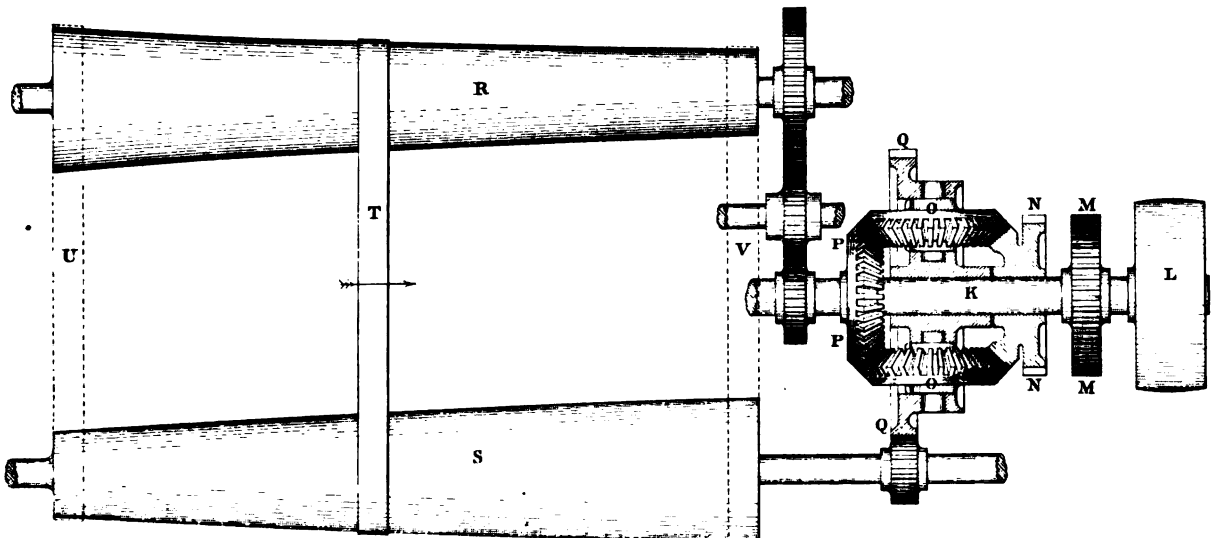


(Proceedings Inst. M.E. 1866. Page 139.)

Scale 1/10 th.

0 5 10 15 20 25 30 *Inches.*

Fig. 18. *Houldsworth's Differential Motion. 1826.*



(Proceedings Inst. M. E. 1866. Page 199.) Scale $\frac{1}{8}$ th. 0 5 10 15 20 25 30 inches.

Eaton's Backing-Off Motion.. 1818.

Fig. 19. *Side Elevation.*

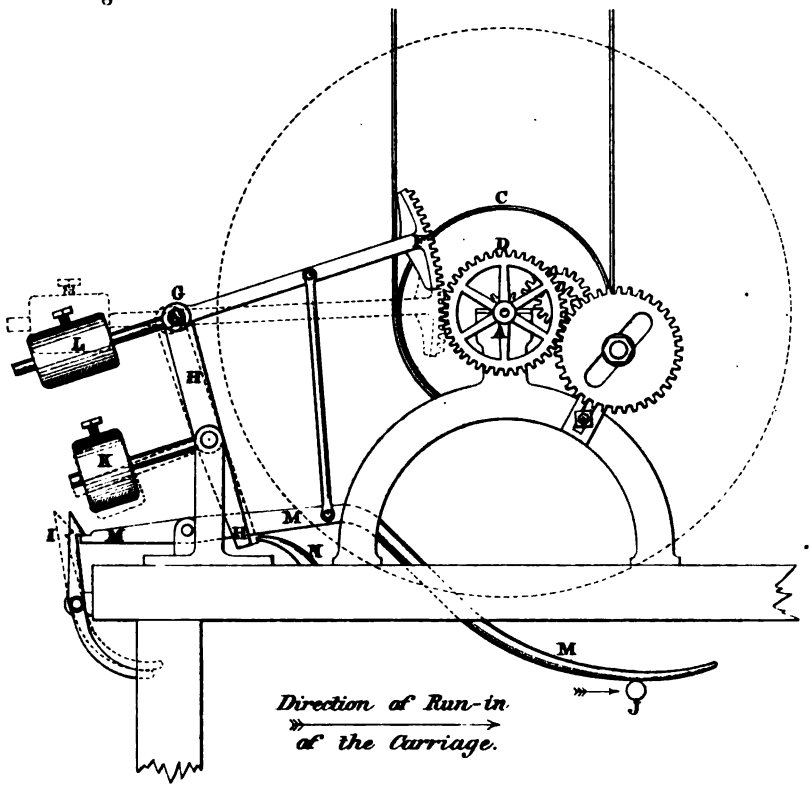
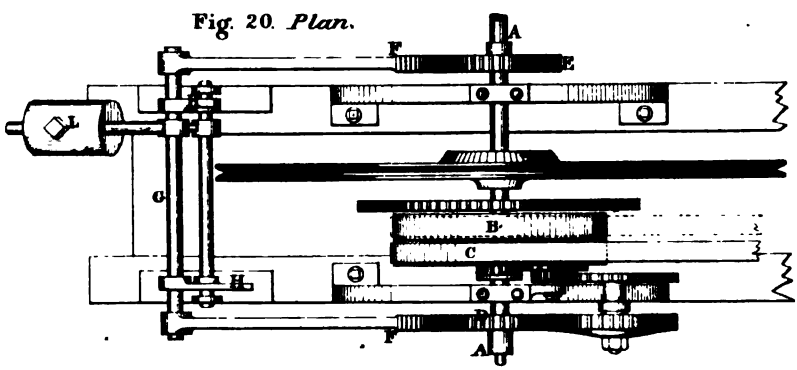


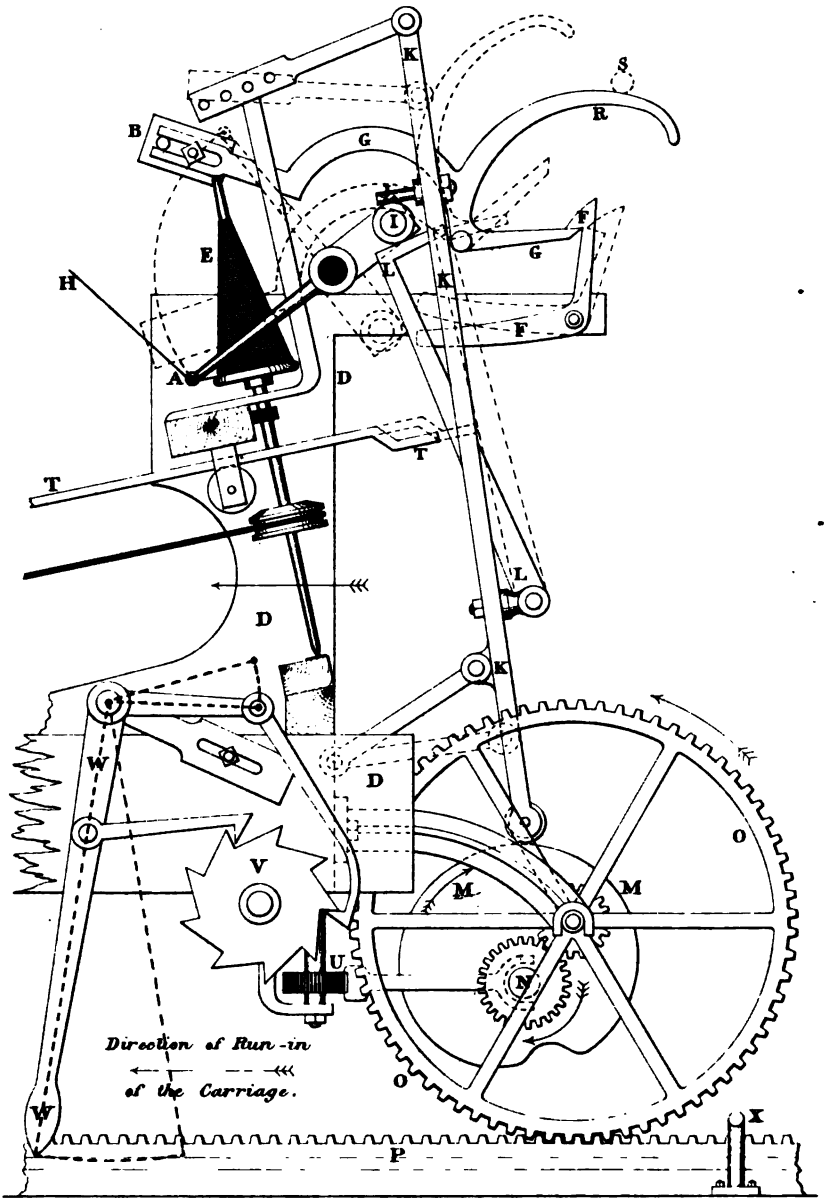
Fig. 20. *Plan.*



(Proceedings Inst. M.E. 1866. Page 199.) *Scale* 1/12 *th*

10 . . . . 5 . . . . 0 10 20 30 inches.

Fig. 21. *Eaton's Faller Motion.* 1818.



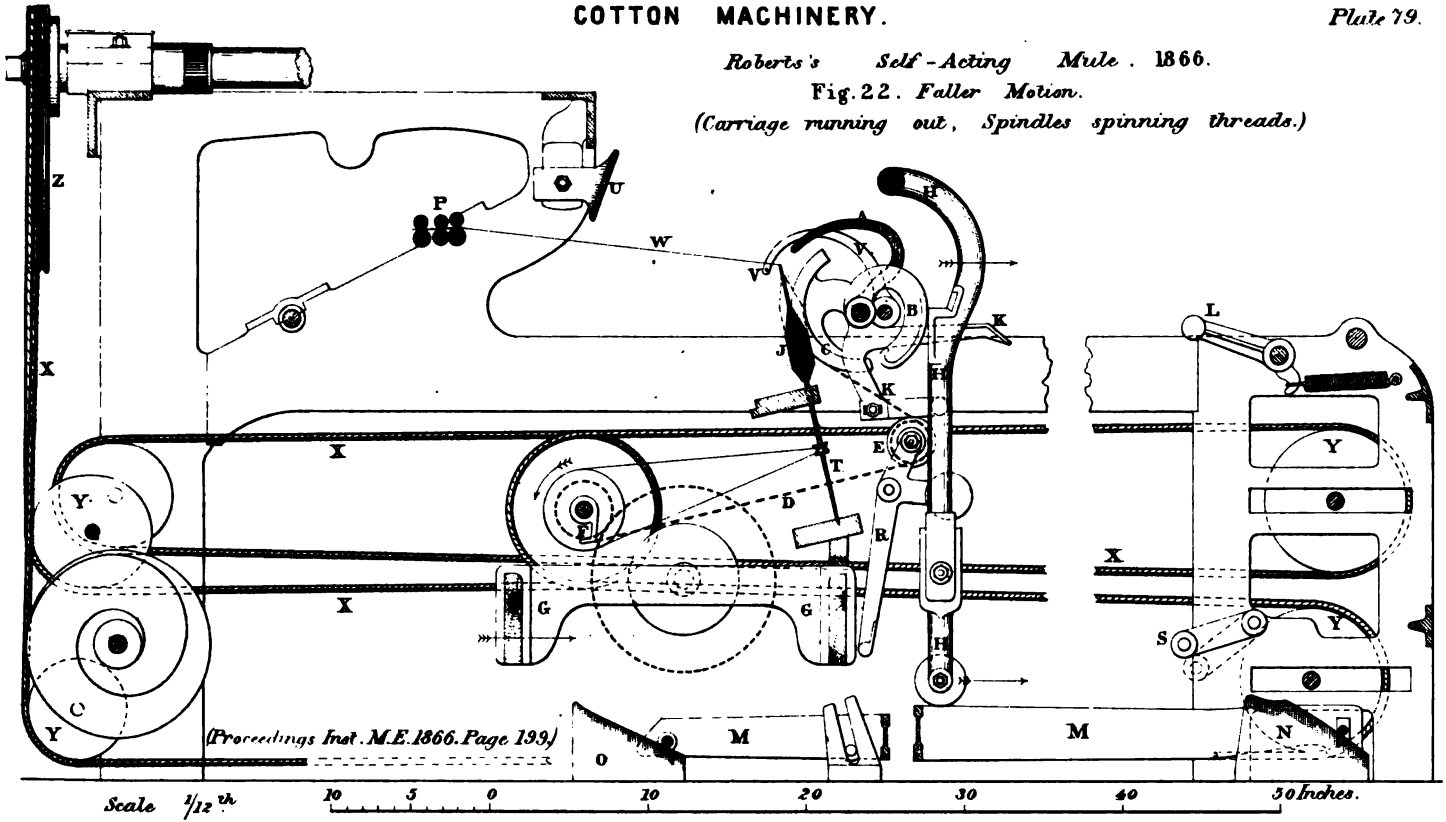
(Proceedings Inst. M.E. 1866. Page 199.) *Scale* 1/6th

0 5 10 15 20 Inches.

Roberts's Self-Acting Mule. 1866.

Fig. 22. *Faller Motion.*

(Carriage running out, Spindles spinning threads.)

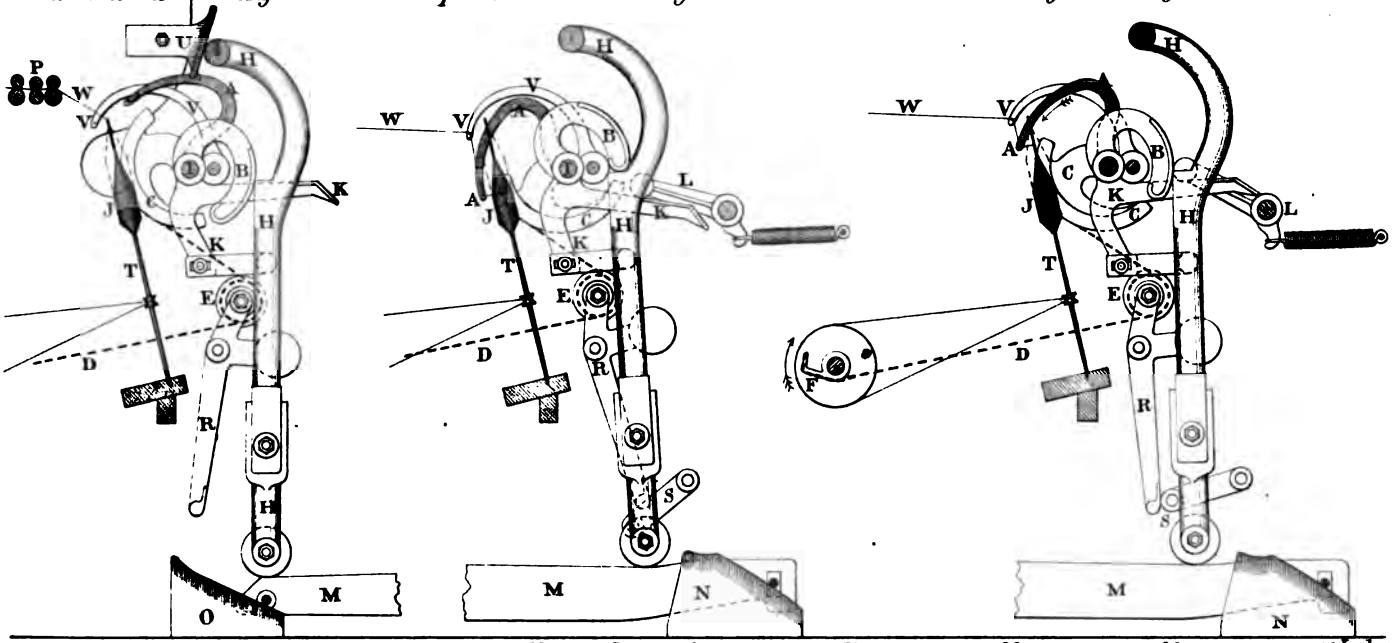


Roberts's Self-Acting Mule. 1866. Faller Motion.

Fig. 25. *Unlocking of Faller at end of winding.*

Fig. 24. *Locking of Faller previous to winding.*

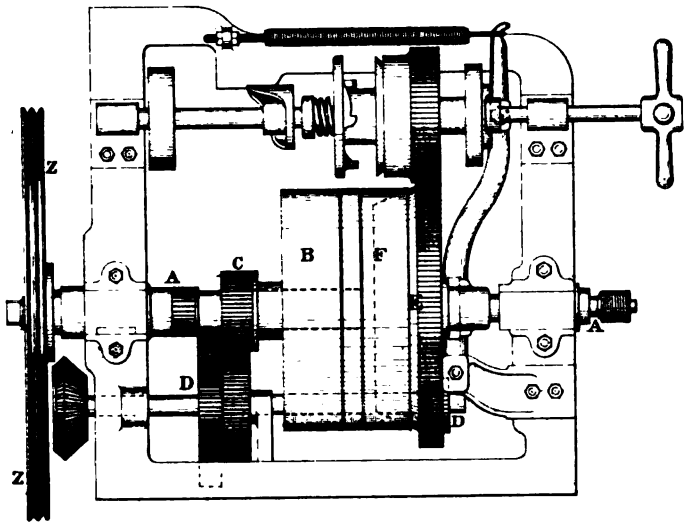
Fig. 23. *Putting-down of Faller during Backing-Off.*



(*Proceedings Inst. M.E. 1866. Page 199.*) Scale 1/12th.

Roberts's Self-Acting Mule. 1866.

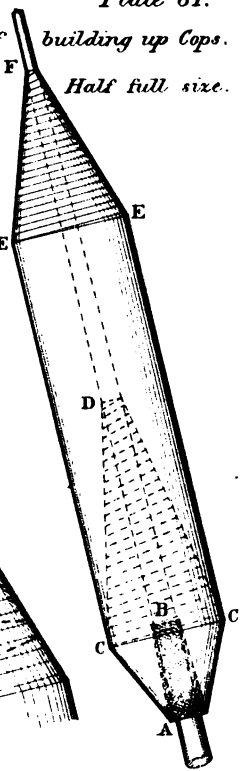
Fig. 28. *Plan of Backing-Off Motion.*



(Proceedings Inst. M.E. 1866. Page 199.) *Scale* 1/12 th.

10 5 0 10 20 30 Inches.

Fig.26. *Mode of building up Cops.*
Half full size.



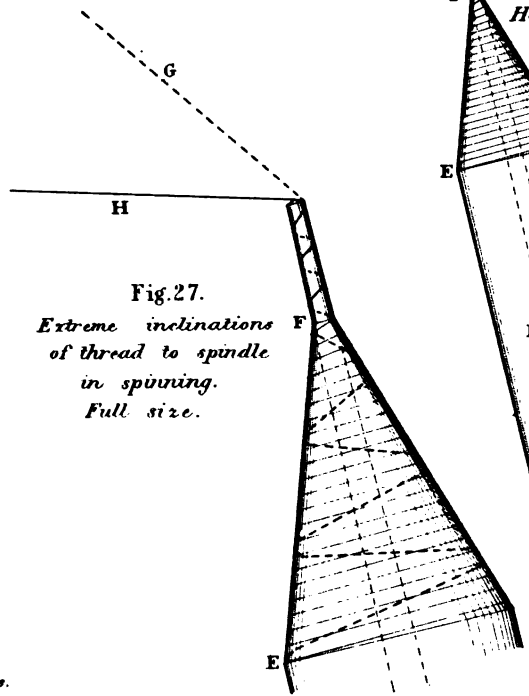
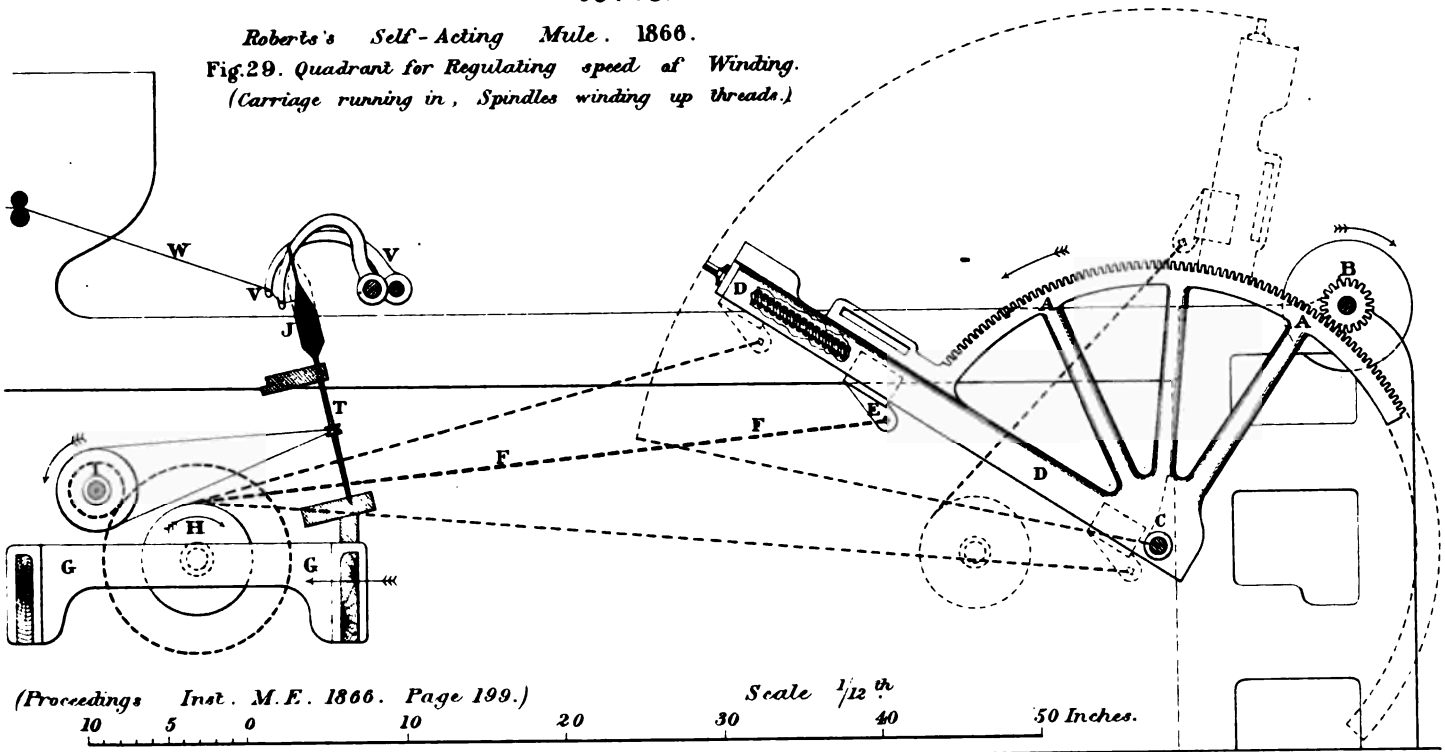


Fig.27.
Extreme inclinations of thread to spindle in spinning.
Full size.

Roberts's Self-Acting Mule. 1866.

Fig.29. *Quadrant for Regulating speed of Winding.*
(Carriage running in, Spindles winding up threads.)



(Proceedings Inst. M.E. 1866. Page 199.)

Scale 1/12th

10 5 0 10 20 30 40 50 Inches.

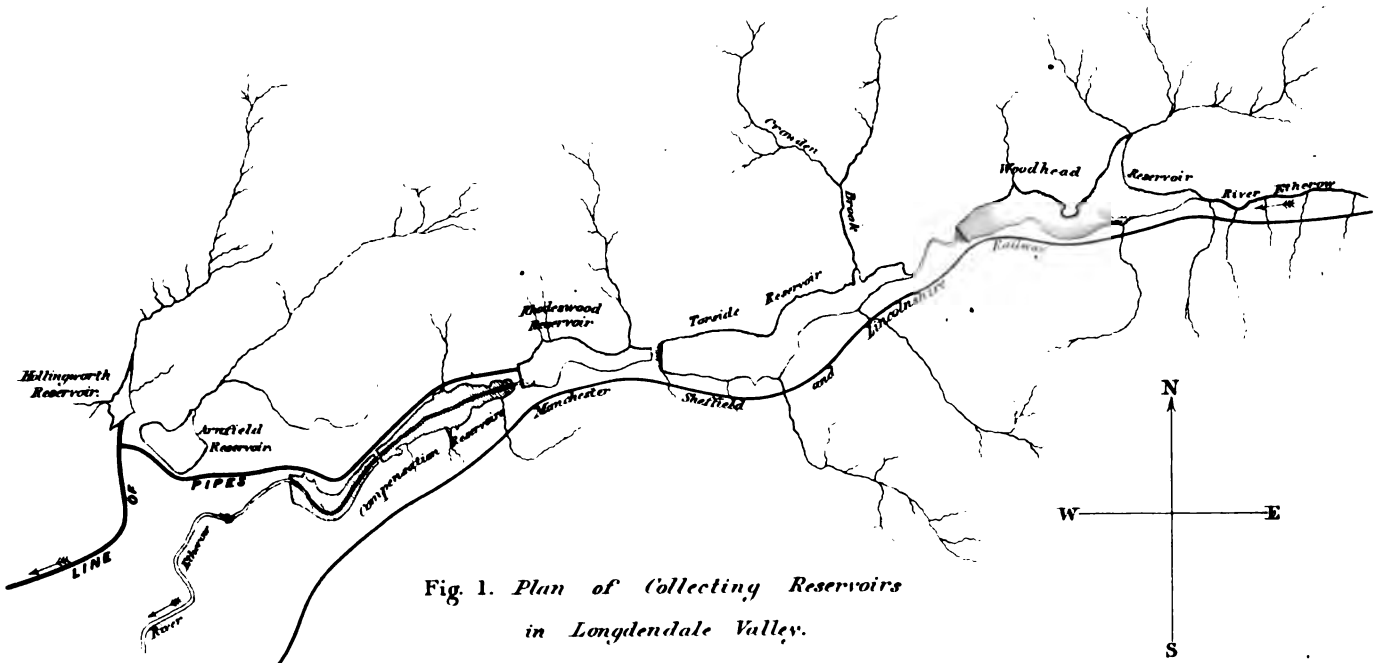


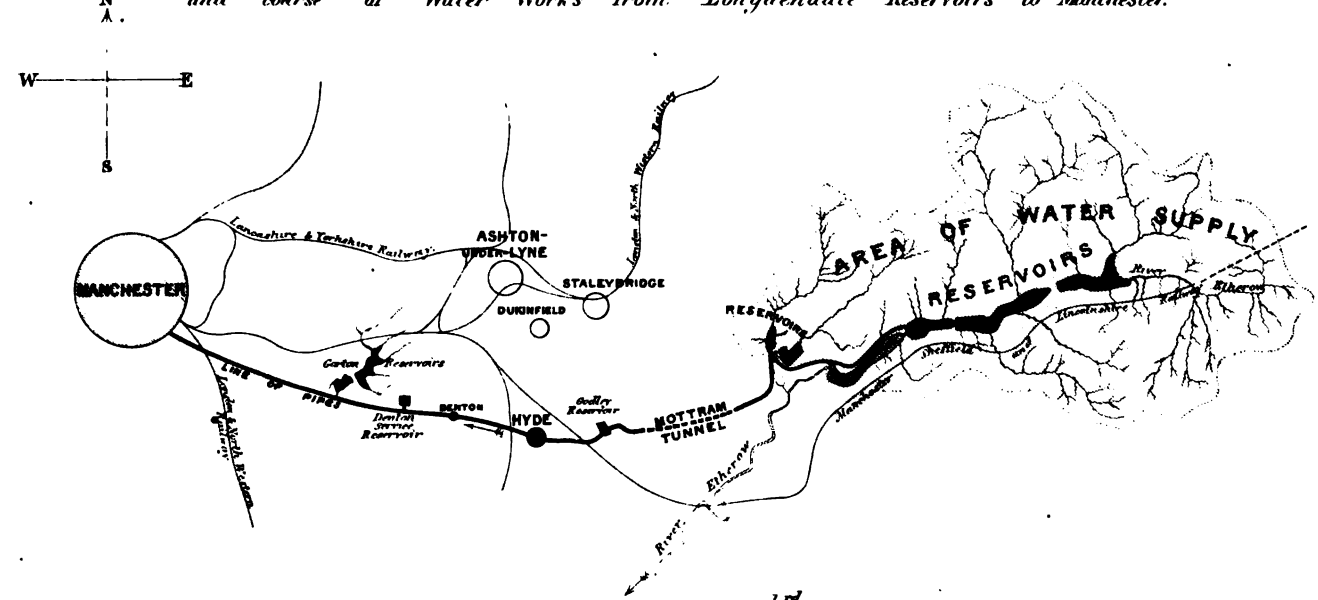
Fig. 1. *Plan of Collecting Reservoirs in Longdendale Valley.*

(Proceedings Inst. M. E. 1866. Page 245.)

Scale 1 inch per mile.

0 1 2 3 4 5 6 Miles.

Fig. 2. *General Plan showing Drainage Area, and course of Water Works from Longdendale Reservoirs to Manchester.*



(Proceedings Inst. M.E. 1866. Page 245.)

MANCHESTER WATER WORKS.

Fig. 4.
Separation of turbid water in Large streams.
(Pure water coloured blue.)

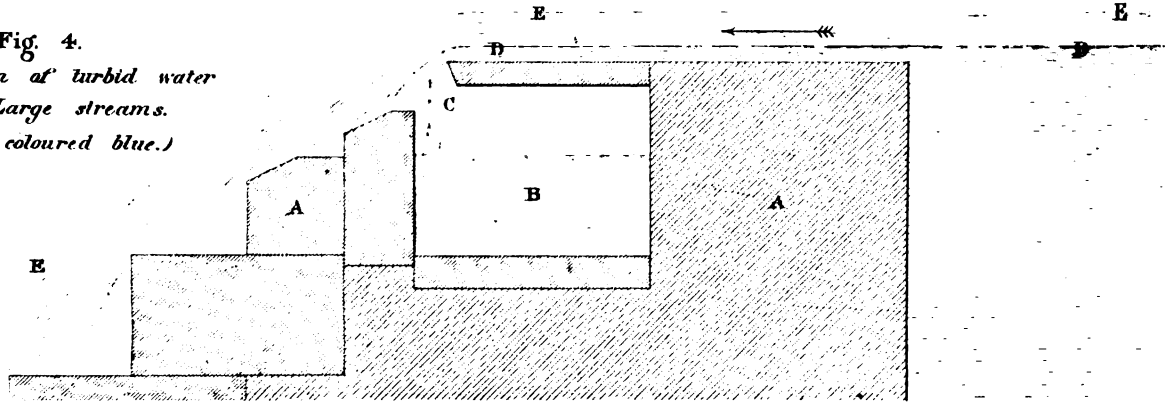
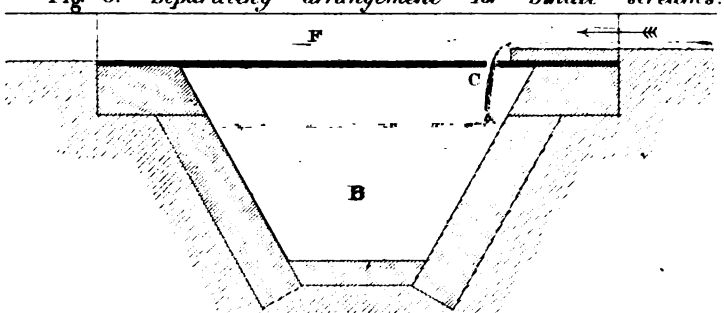


Fig. 5. *Separating arrangement for Small streams.*



(Proceedings Inst. M.E. 1866. Page 245.)

Scale $\frac{1}{50}$ *th*

Fig. 6. *Plan.*

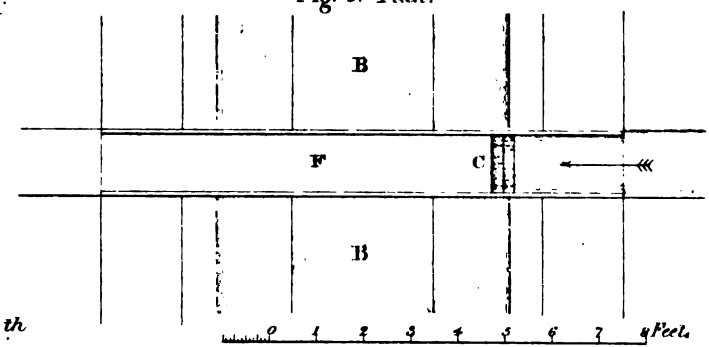


Fig. 4.
Separation of turbid water in Large streams.
(Pure water coloured blue.)

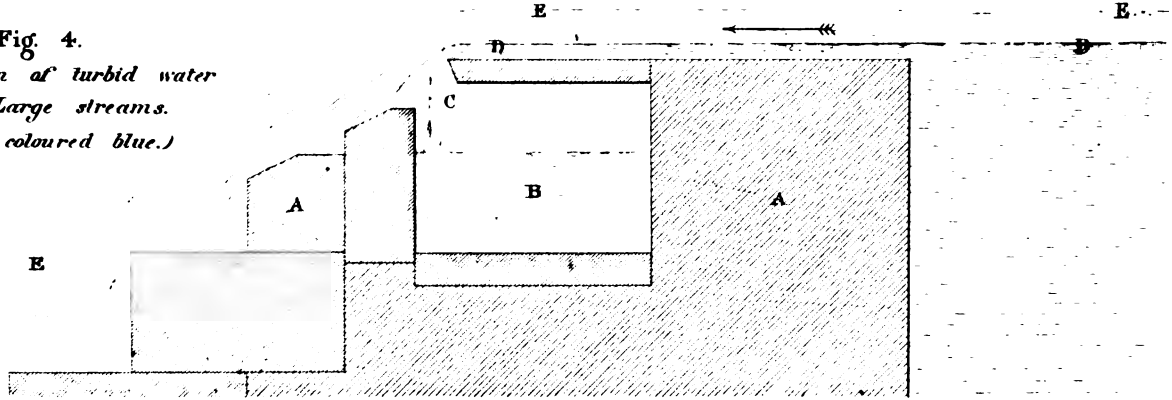
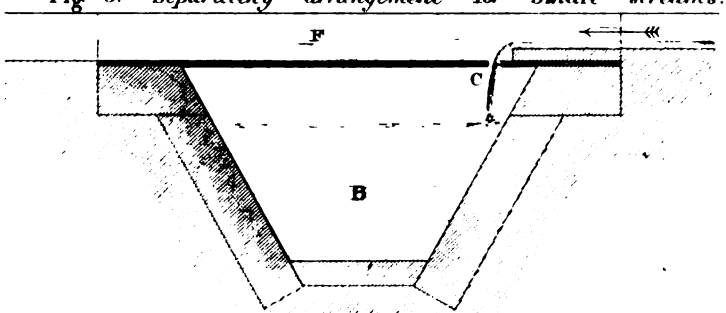


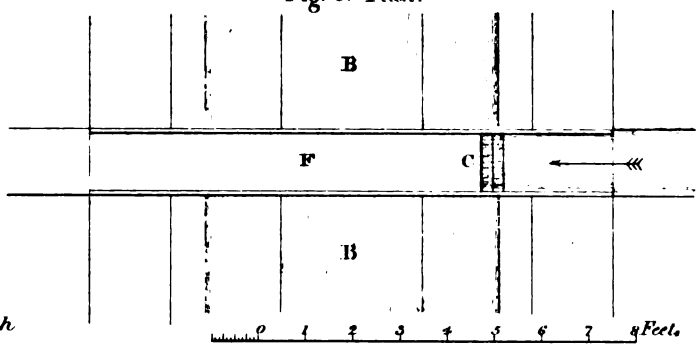
Fig 5. *Separating arrangement for Small streams.*



(Proceedings Inst. M.E. 1866. Page 245.)

Scale $\frac{1}{50}$ th

Fig. 6. *Plan.*



MANCHESTER WATER WORKS. *Plate 87.*

48 inch Sluice Valve at large reservoirs.

Fig. 7. *Vertical Section.* Fig. 8. *Sectional Plan.*

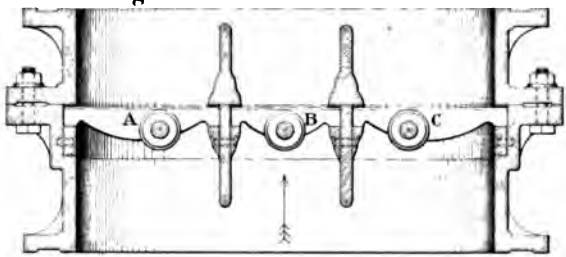
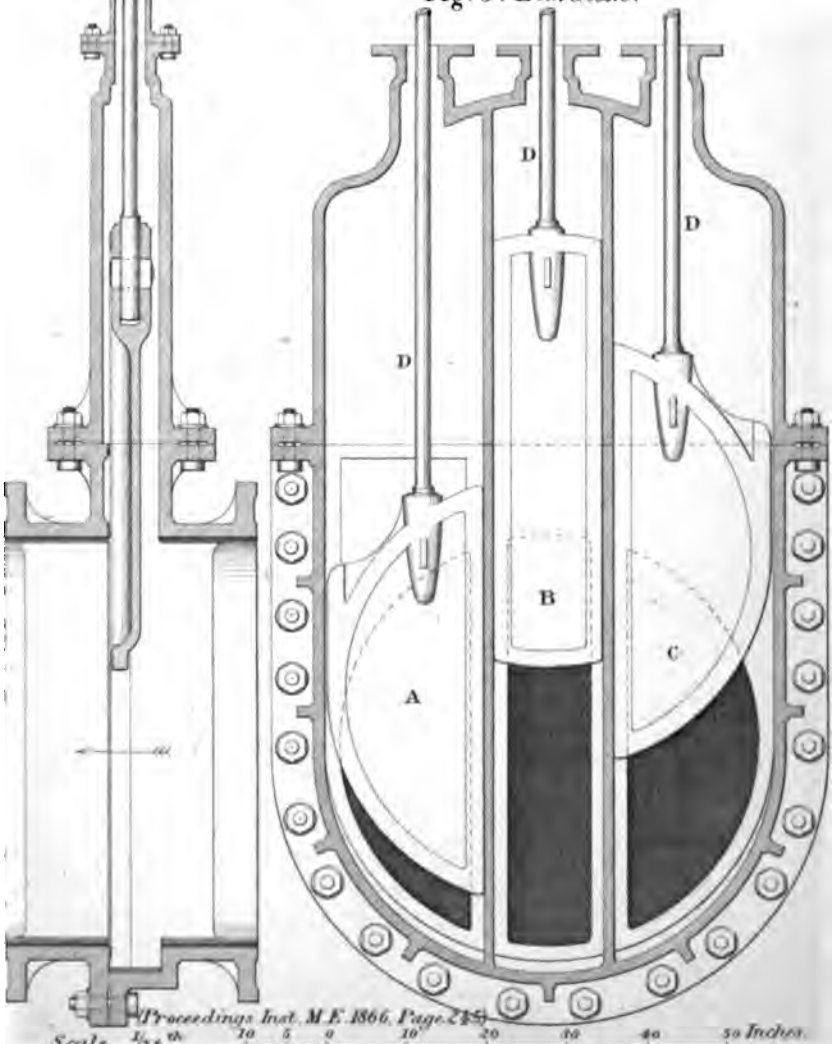


Fig. 9. *Elevation.*



MANCHESTER WATER WORKS.

Plate 88.

40 *inch Reflux Valve.*

Fig. 10. *Vertical Section.*

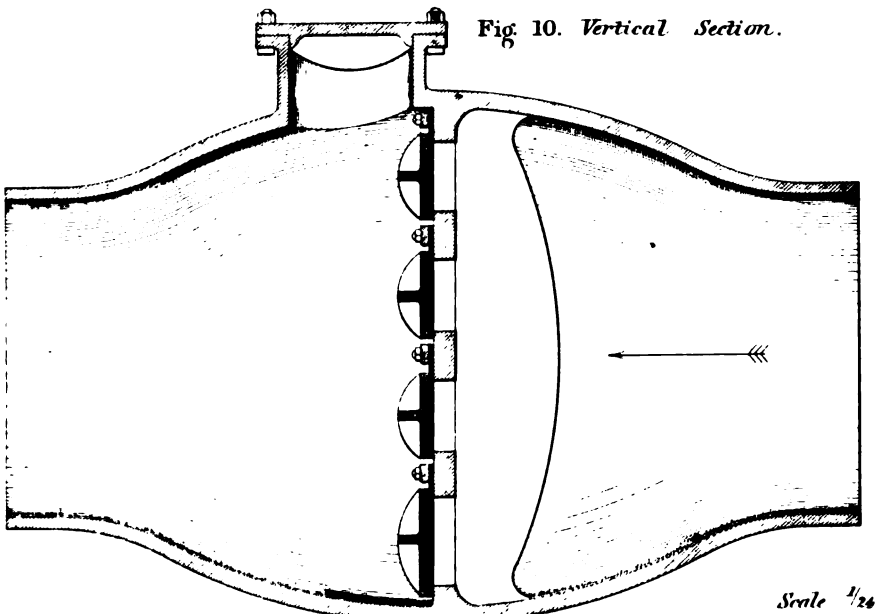
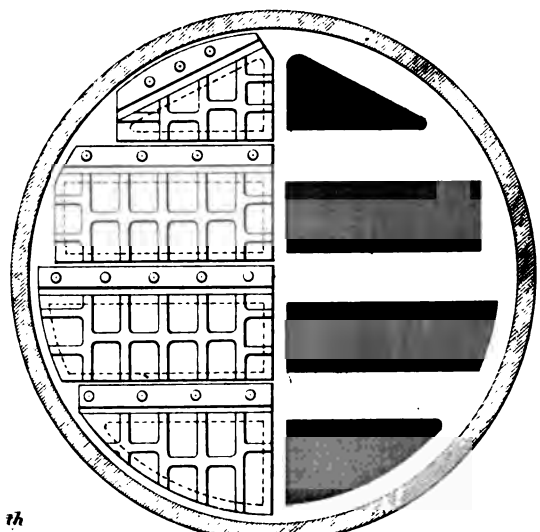


Fig. 11. *Elevation.*

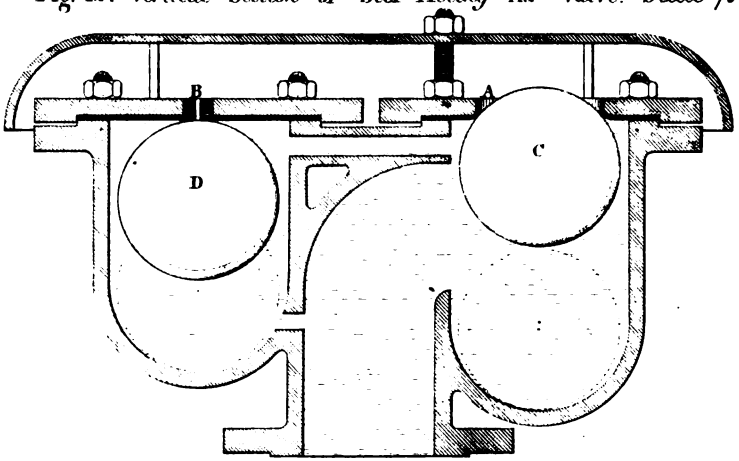


Scale 1/24 th

0 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

(*Proceedings Inst. M.E. 1866. Page 245.*)

Fig. 12. *Vertical Section of Self-Acting Air Valve. Scale 7/8 in.*



Hydrant or Fire-Cock.

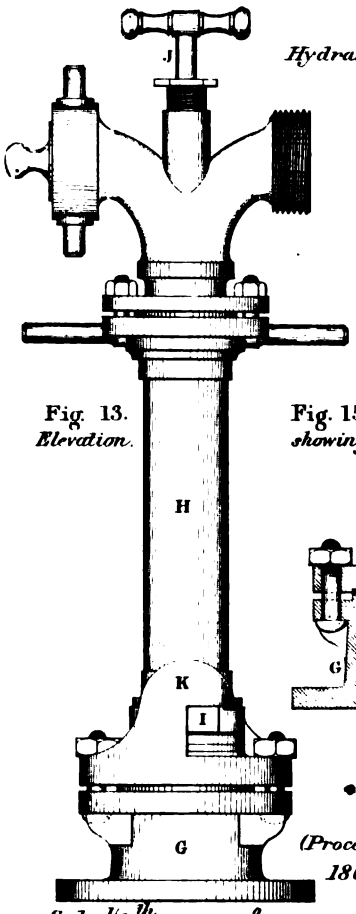
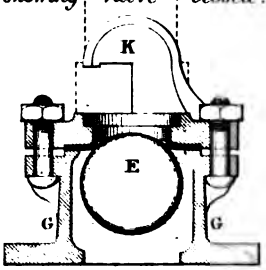


Fig. 13. *Elevation.*

Fig. 15. *Vertical Section showing Valve closed.*



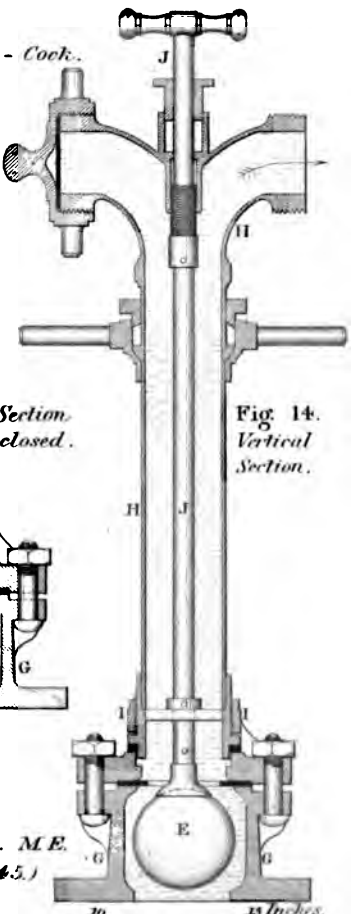


Fig. 14. *Vertical Section.*

(*Proceedings Inst. M.E. 1866. Page 245.*)

Scale 1/6 in.

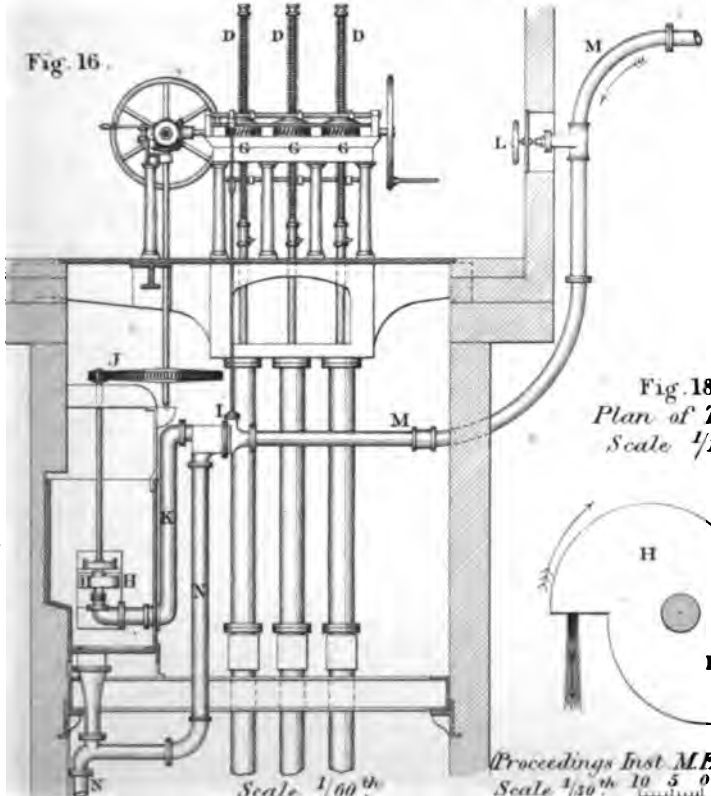
0 5 10 15 *Inches.*

MANCHESTER WATER WORKS.

Plate 90.

Turbine for opening Sluice Valves at reservoirs.

Fig. 16.



Scale 1/60th

Fig. 18.
Plan of Turbine.
Scale 1/10th

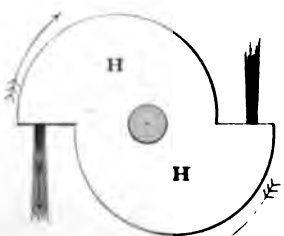
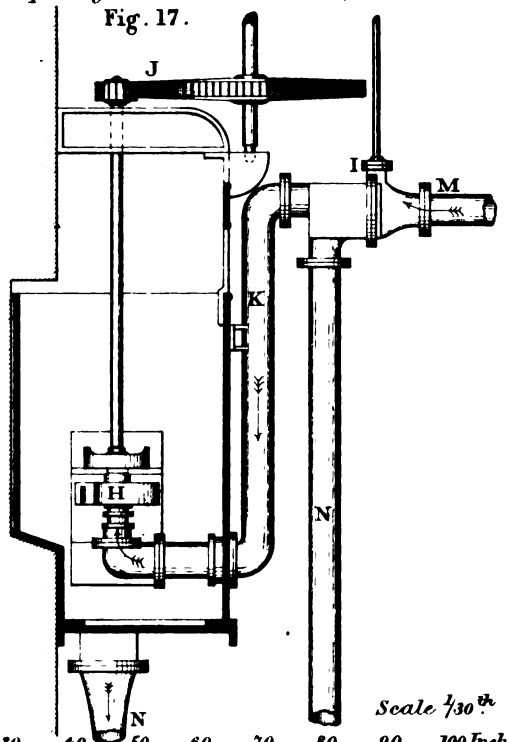


Fig. 17.



Scale 1/30th

Scale 1/30th 10 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

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Gauge Sluice in watercourses.
Scale 1/32nd

Fig. 19.
Elevation.

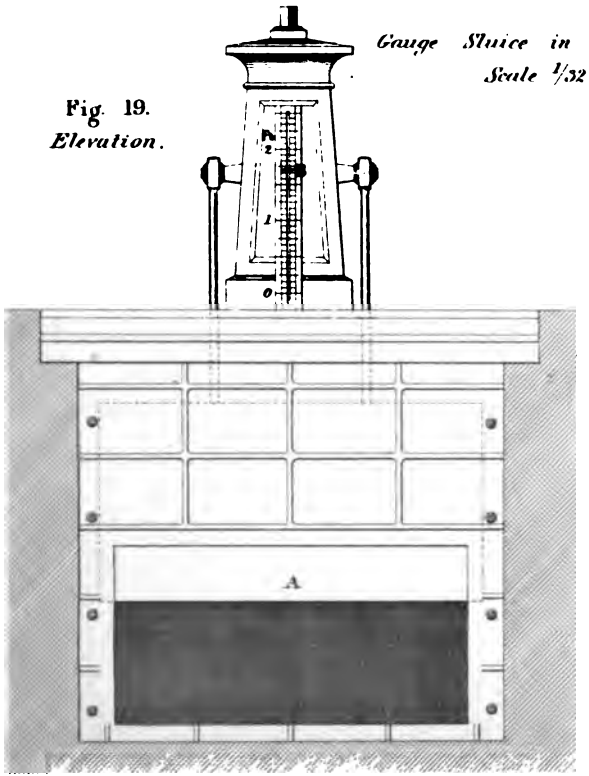


Fig. 20.
Vertical Section.

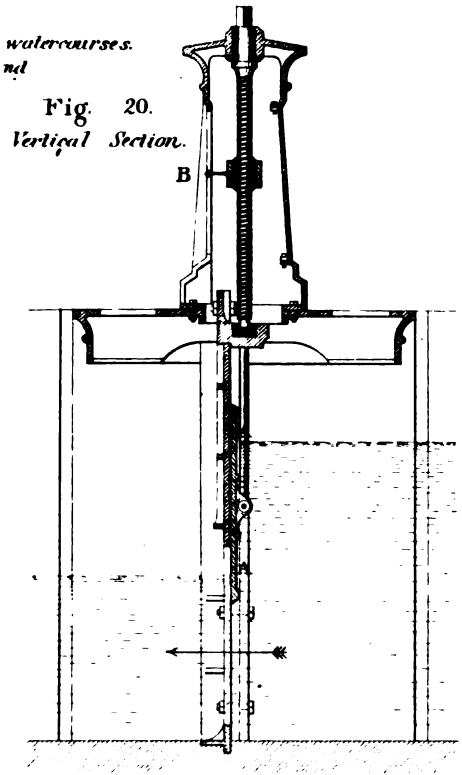


Fig. 21. *Sectional Plan of Headstock.*
Scale 1/16th

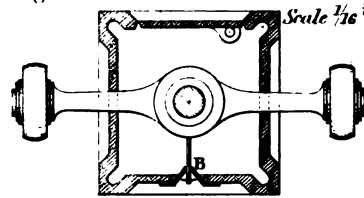


Fig. 22. *Enlarged Plan of Index.*
Scale 1/4th

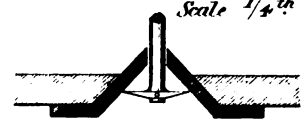
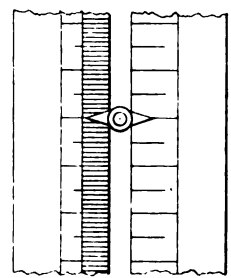


Fig. 23. *Elevation of Index.*



Scale 1/32nd 10 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

(Proceedings Inst. M.E. 1866. Page 245.)

MANCHESTER WATER WORKS.

Transverse Vertical Sections of Gauge Plate at Godley Reservoir. *Rectangular Openings, 6 ft. wide by 6 ins. high.*

Fig. 24. *Coefficient* 5·6

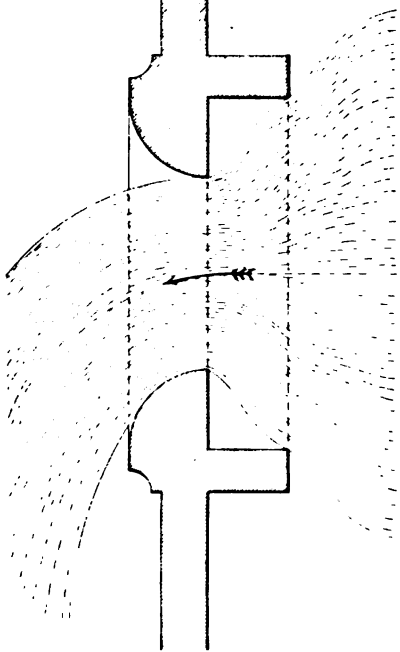


Fig. 25. *Coefficient* 7·0

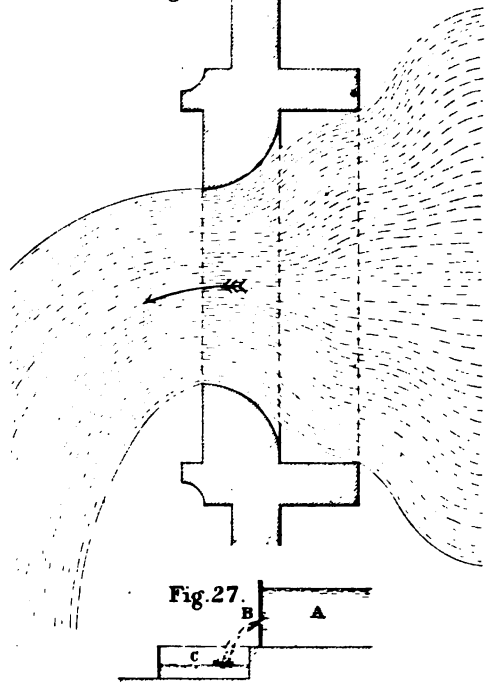


Fig. 26. *Coefficient* 7·6

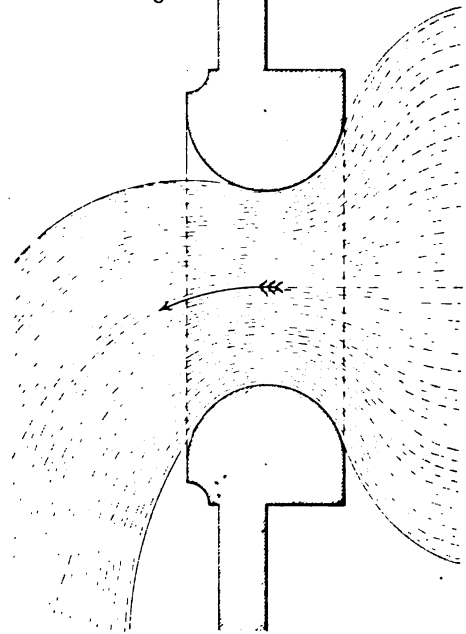


Fig. 27.

Scale 1/6 th

0 1 2 3 4 5 6 7 8 9 10 Inches.

(Proceedings Inst. M.E. 1866. Page 245.)

Gauging of Compensation Water for mills.

Fig. 28. *Plan.*

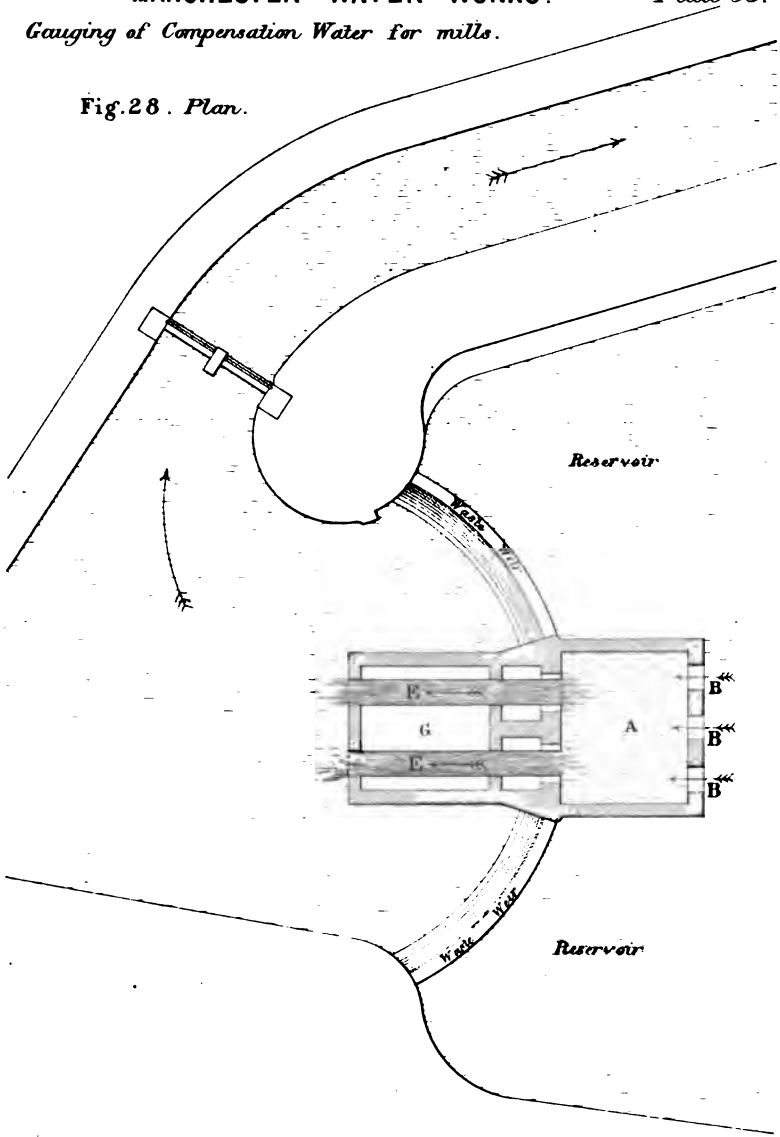
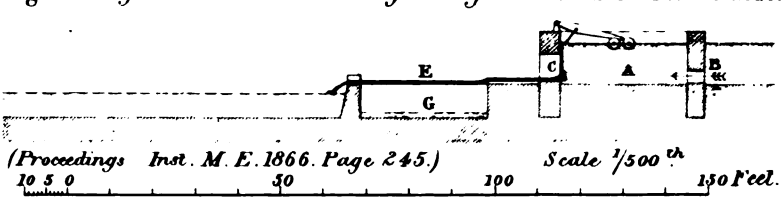
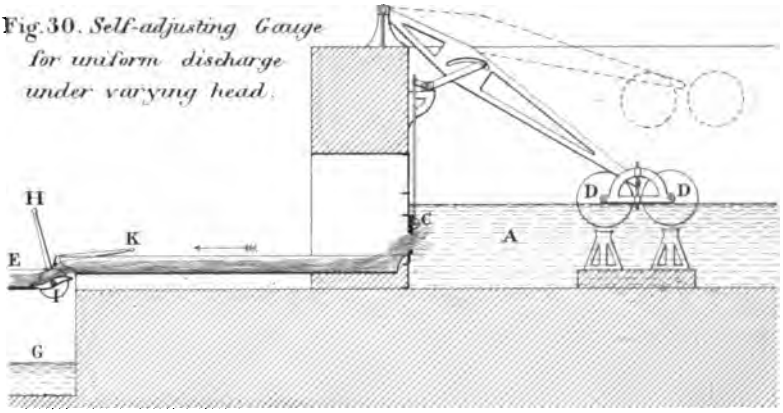


Fig. 29. *Longitudinal Section through Gauge Basin and Test Basin.*



(Proceedings Inst. M. E. 1866. Page 245.) *Scale 1/500th*

Fig. 30. *Self-adjusting Gauge for uniform discharge under varying head.*



Scale 1/120th 10 5 0 10 20 Feet.

Fig. 31. *Elevation of Gauge Plate.* Scale 1/24th

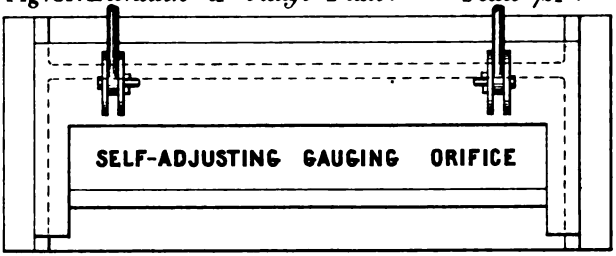
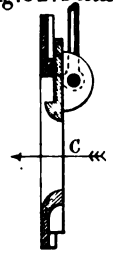


Fig. 32. *Section.*



Reversing Tumbler in Discharge Trough. Scale 1/24th

Fig. 33. *Ordinary open position.*

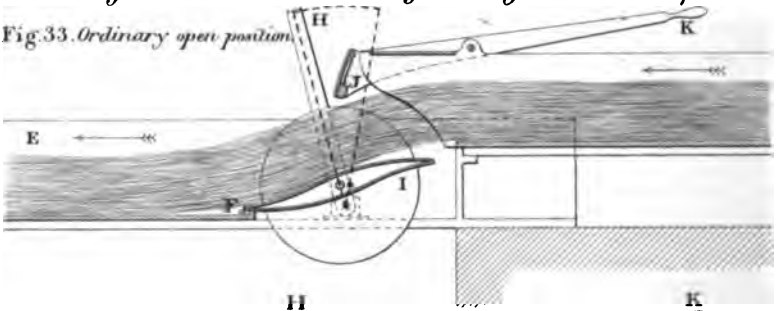
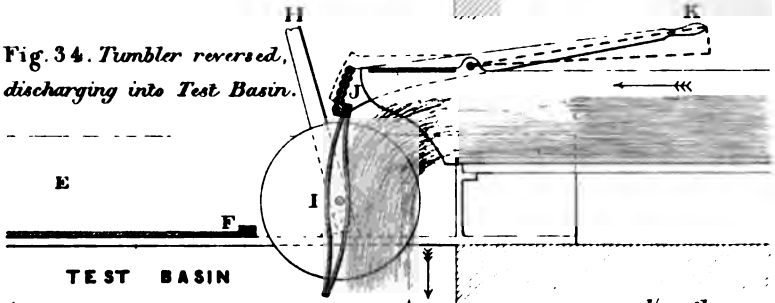


Fig. 34. *Tumbler reversed, discharging into Test Basin.*



(Proceedings Inst. M.E. 1866. Page 245)

Scale 1/24th

Ins. 12 6 0 1 2 3 4 5 6 Feet.

SELF - ADJUSTING INJECTOR. *Plate 95.*

Fig 1. *Original Giffard's Injector.*
Scale 1/10 th

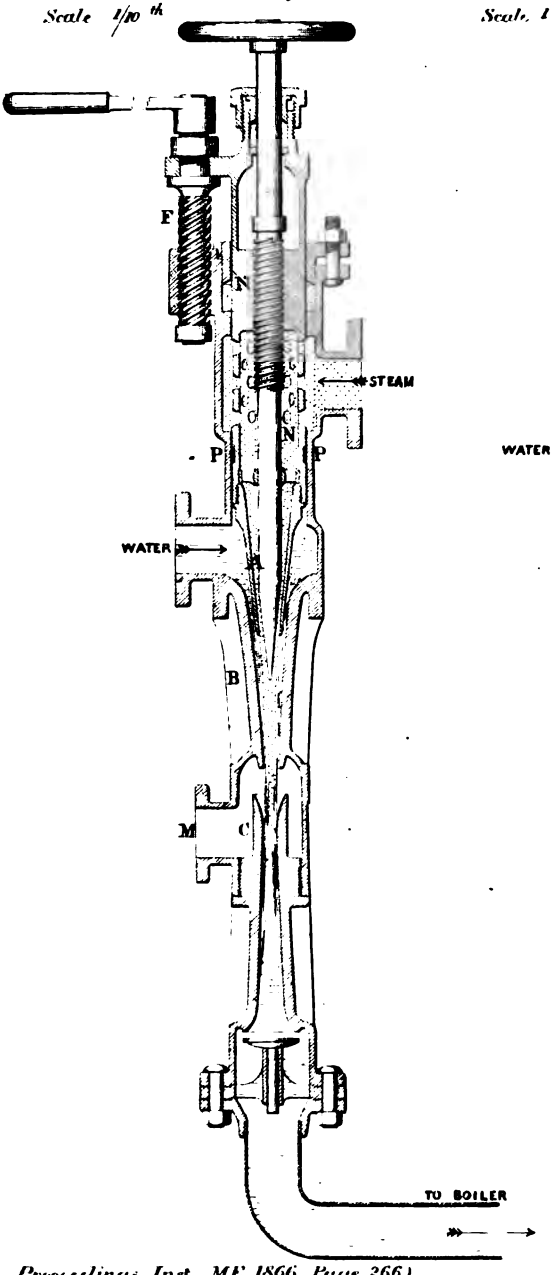


Fig 2. *Rack and Pinion Injector.*
Scale 1/10 th

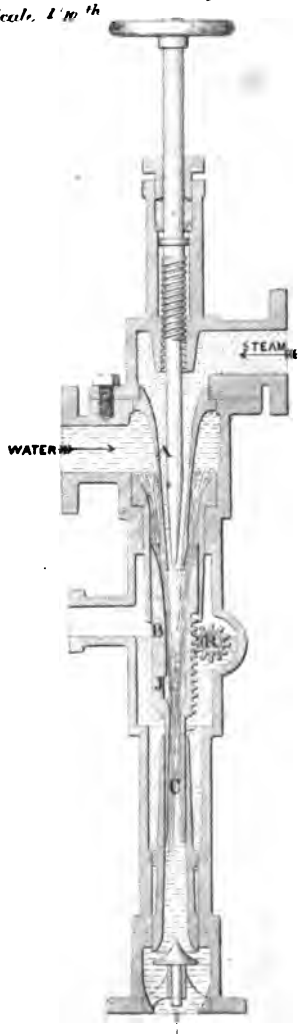


Fig. 3. *Transverse section at J.*
Scale 1/5 th

Proceedings Inst ME 1866. Page 266)

Scale 1/10 th 0 5 10 15 20 25 30 Inches

SELF-ADJUSTING INJECTOR.

Plate 96.

Sellers' Self-Adjusting Injector.

Fig 4. *Vertical Section.*

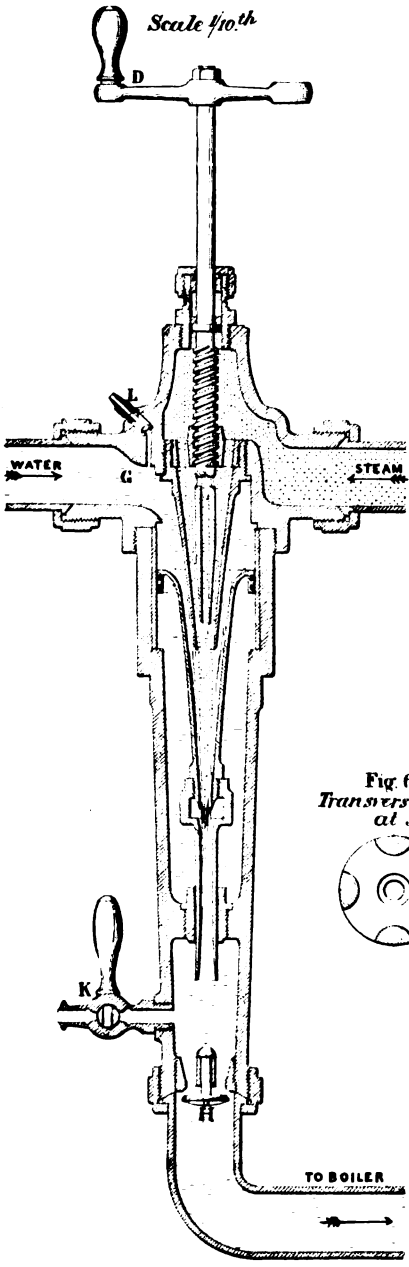


Fig 5. *Vertical Section, enlarged.*

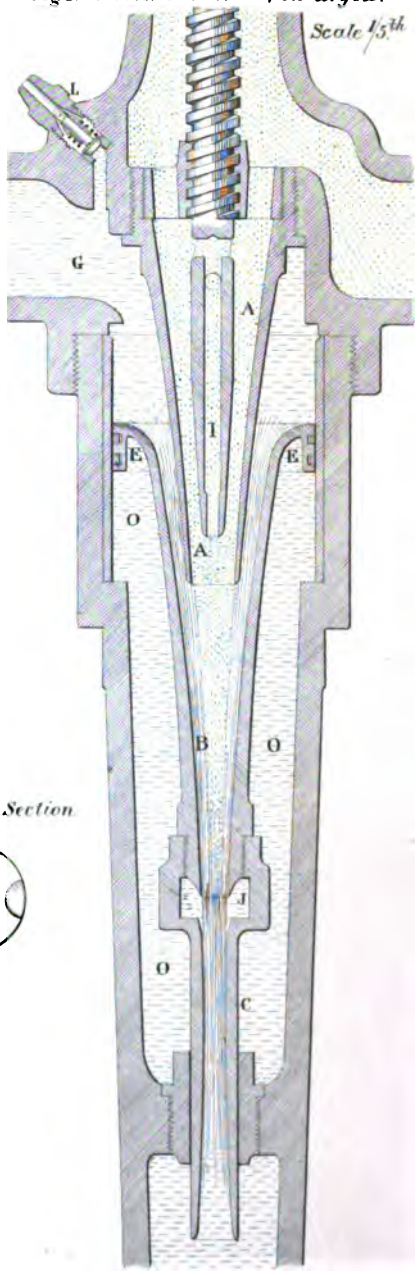


Fig. 6.
Transverse Section at J.

(Proceedings Inst. M.E. 1866. Page 266)

Scale 1/10th

0 5 10 15 20 25 30 inches

SELF-ADJUSTING INJECTOR.

Plate 97.

Self-Starting and Self-Adjusting Injector.

Fig 7. *Scale 1/10th*

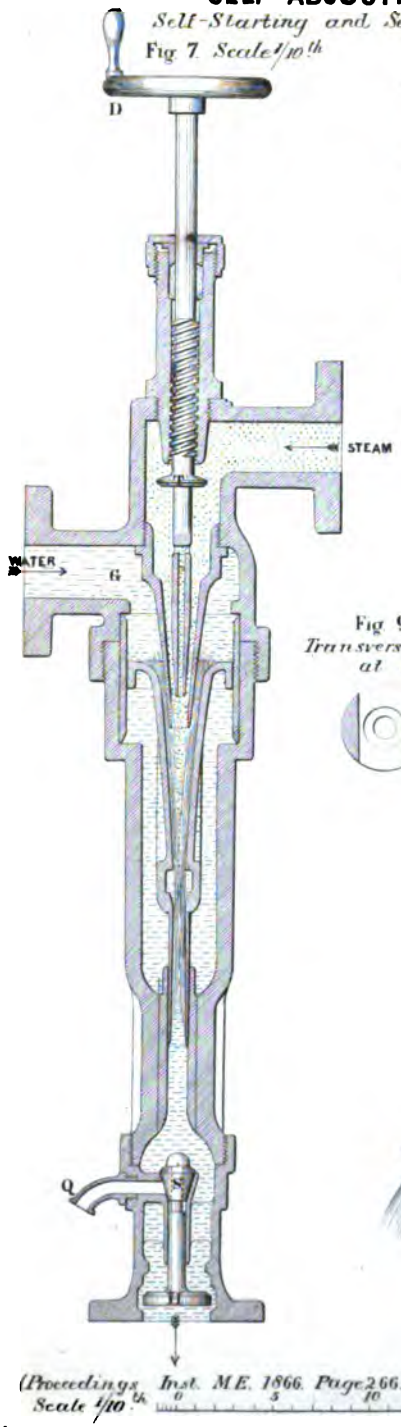


Fig 8.
Scale 1/5th

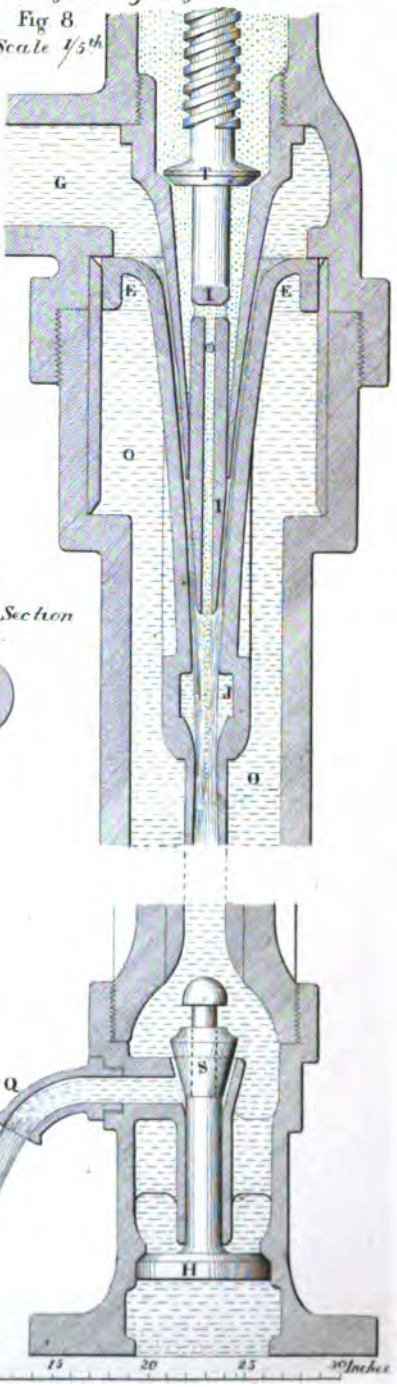


Fig 9.
Transverse Section at J.

(*Proceedings Inst. M.E. 1866. Page 266.*)

Scale 1/10th

0 5 10 15 20 25 30 Inches

Fig. 10. *Injector with Double-Stuffing-Box, and shielded steam nozzle.* *Scale 1/10 th*

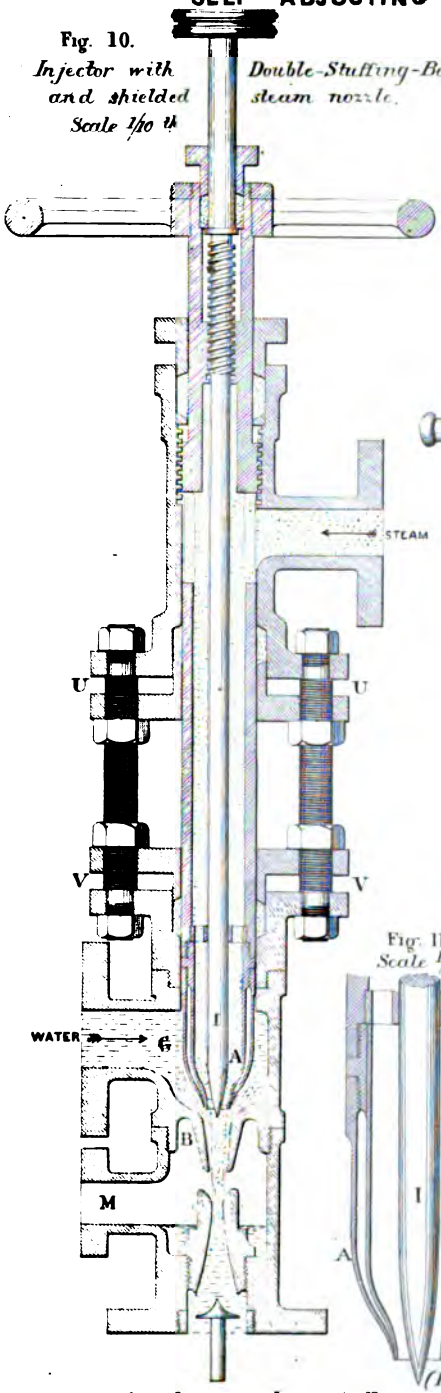
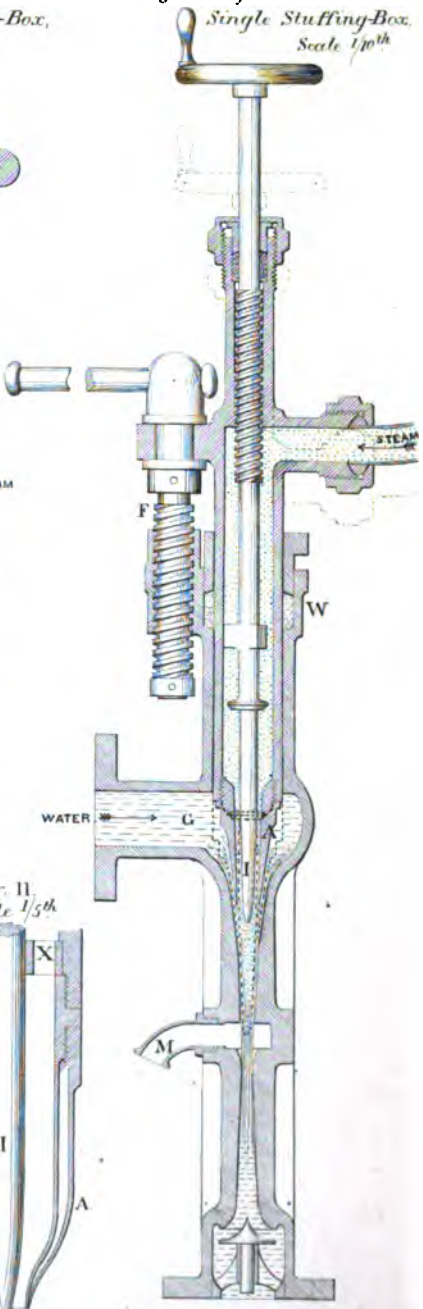


Fig. 11. *Scale 1/5th*

Fig 12. *Injector with Single Stuffing-Box.* *Scale 1/10th*



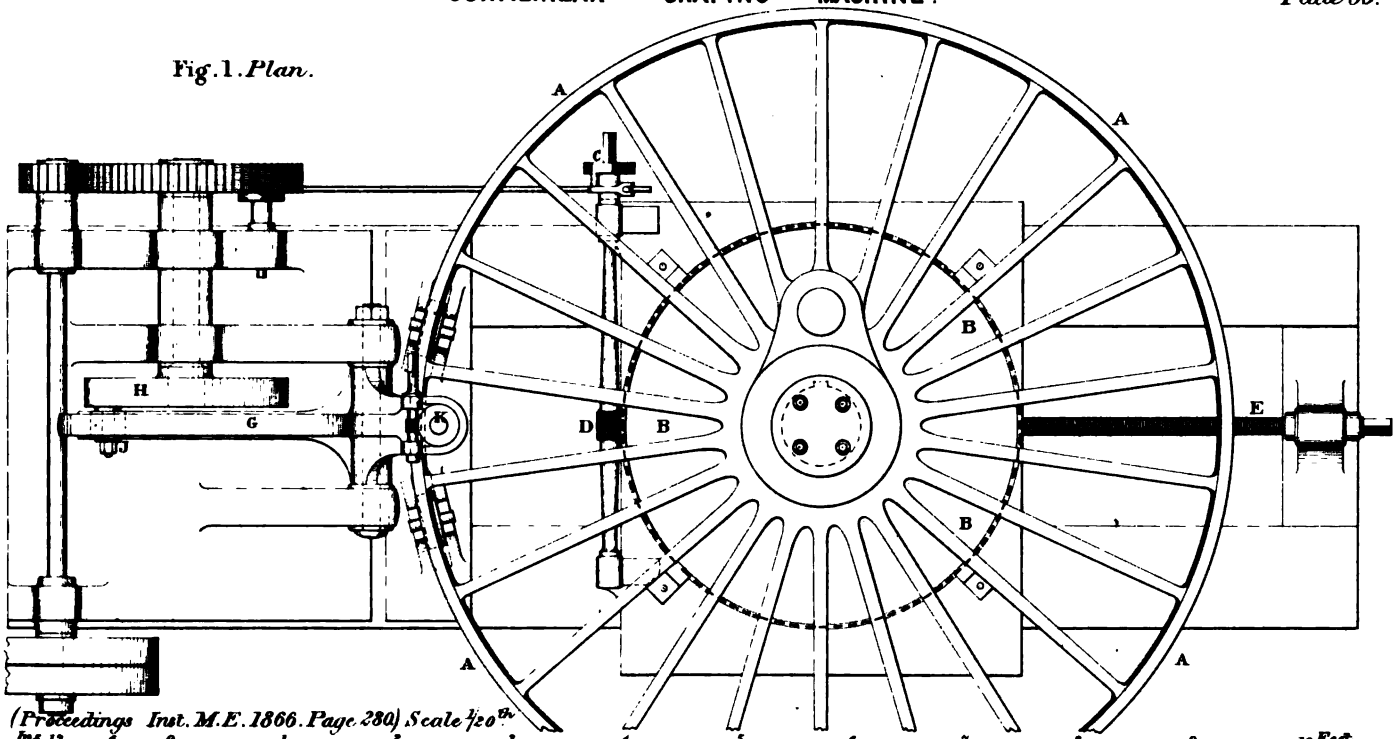
(Proceedings Inst. ME. 1866. Page 266)

Scale 1/10 th 0 5 10 15 20 25 30 Inches

CURVILINEAR SHAPING MACHINE.

Plate 99.

Fig. 1. *Plan.*



(*Proceedings Inst. M.E. 1866. Page 280*) Scale 1/20th

CURVILINEAR SHAPING MACHINE.

Plate 100.

Fig. 2. *Longitudinal Section.*

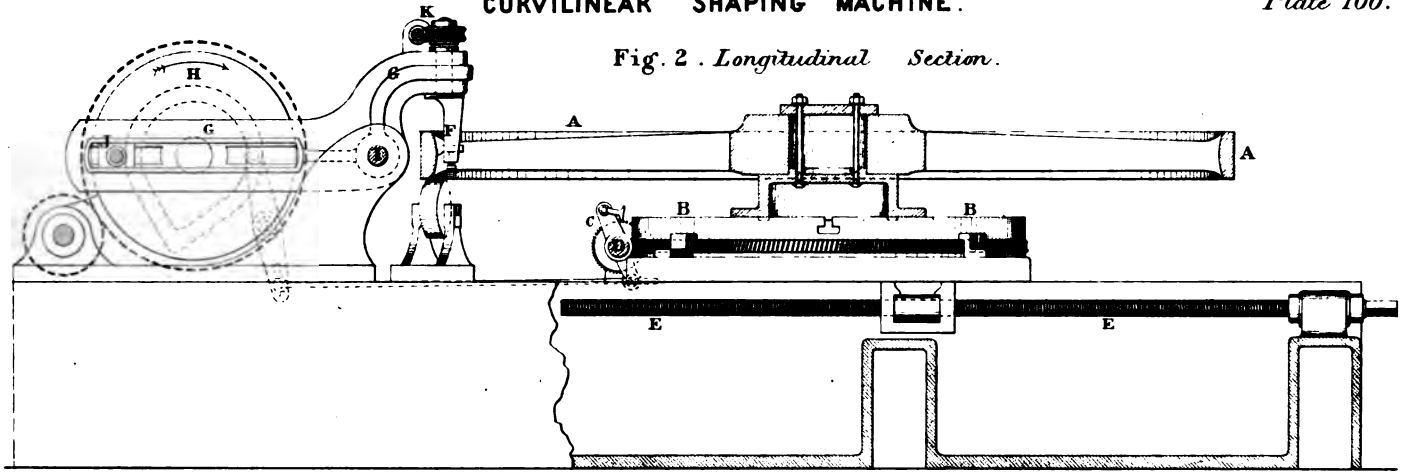


Fig. 3.

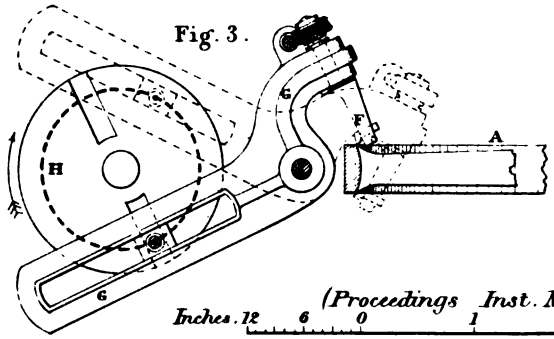
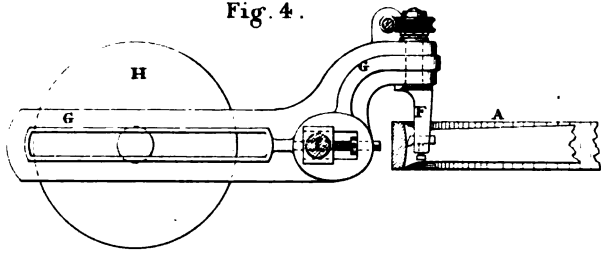


Fig. 4.



(*Proceedings Inst. M. E. 1866. Page 280.*)

Scale 1/20th

Inches. 12 6 0 1 2 3 4 5 6 7 8 Feet.

CURVILINEAR SHAPING MACHINE.

Plate 101.

Fig. 5.

Back Elevation.

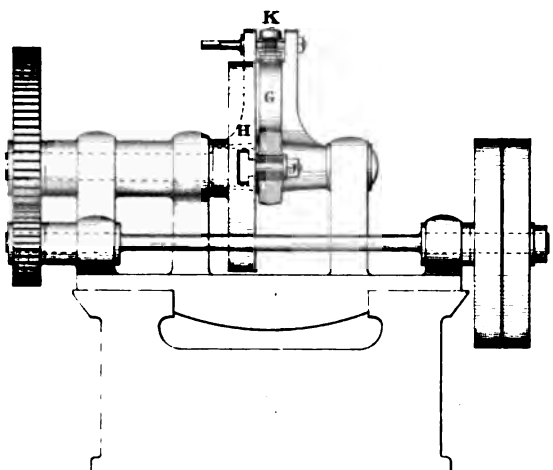
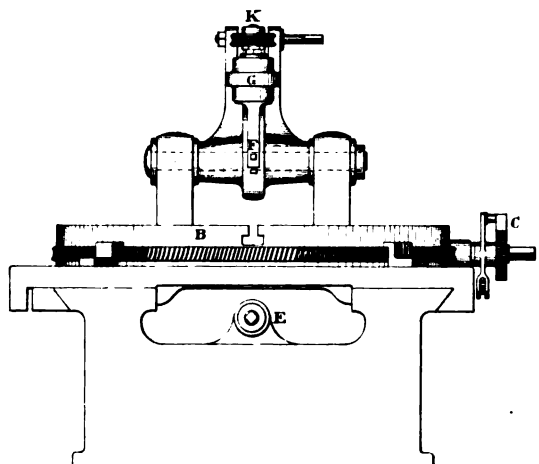


Fig. 6.

Front Elevation.



(Proceedings Inst. M.E. 1866. Page 280.) *Scale 1/20th* Inches 12 6 0 1 2 3 4 5 Feet.

CURVILINEAR SHAPING MACHINE. *Plate 102.*

Detail of Tool, enlarged.

Fig. 7.

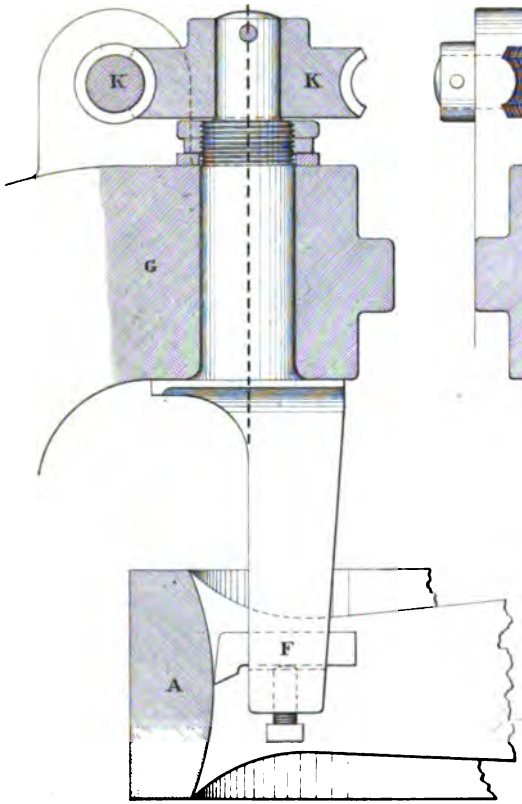


Fig. 8.

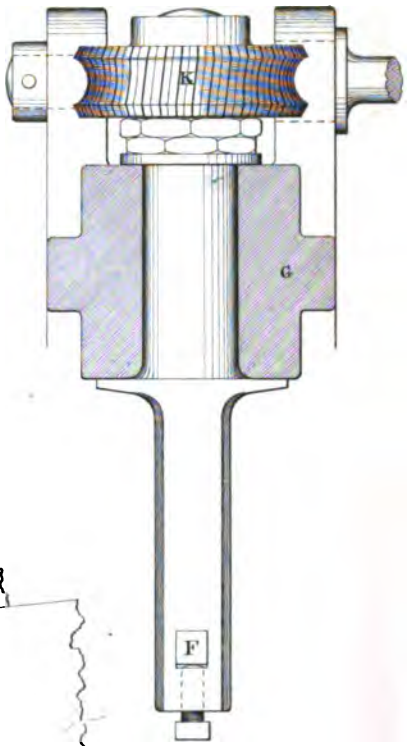


Fig. 9.

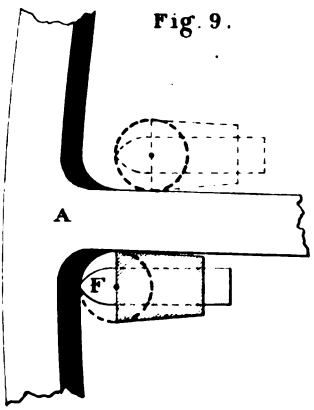
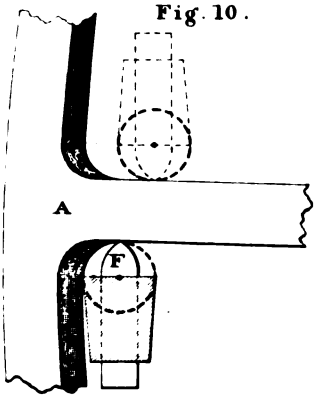


Fig. 10.



(Proceedings Inst. M. E. 1866. Page 280)

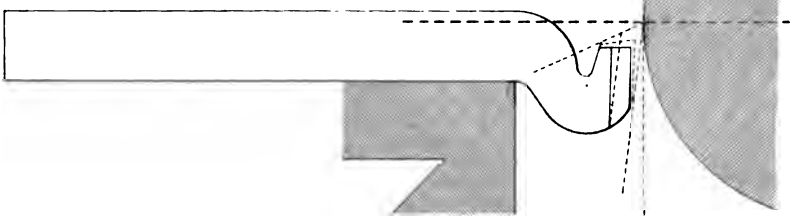
Scale 1/4th

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

IMPROVED TOOL AND HOLDER.

Plate 103

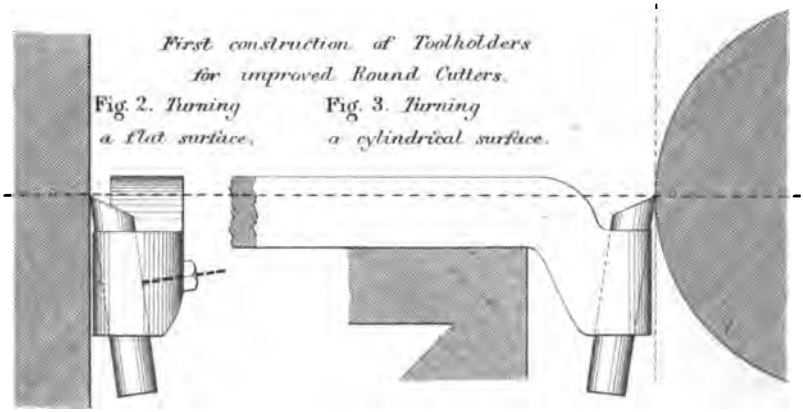
Fig. 1. *Ordinary Diamond-pointed Tool.*



First construction of Toolholders for improved Round Cutters.

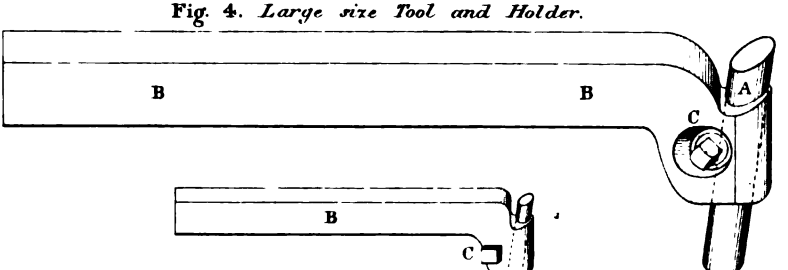
Fig. 2. *Turning a flat surface.*

Fig. 3. *Turning a cylindrical surface.*



Improved construction of Toolholder for Round Cutters.

Fig. 4. *Large size Tool and Holder.*



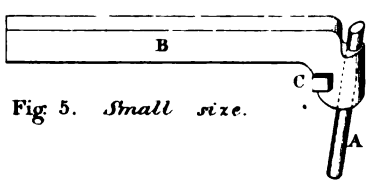


Fig. 5. *Small size.*

Fig. 6. *Round Steel Bar forming Cutters.*

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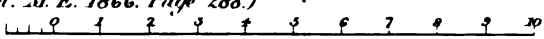
Scale 1/4th



IMPROVED TOOL AND HOLDER.

Improved Tool turning both cylindrical and flat surfaces.

Fig. 7.

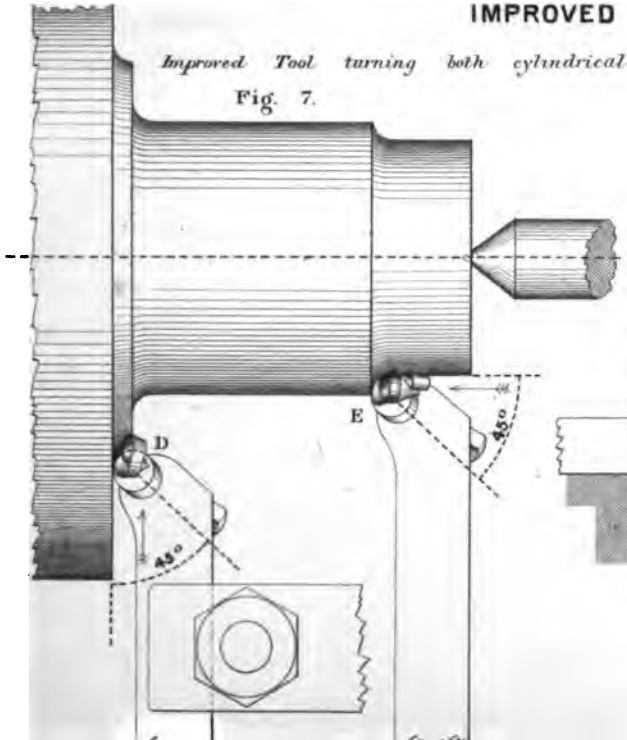


Fig. 8.

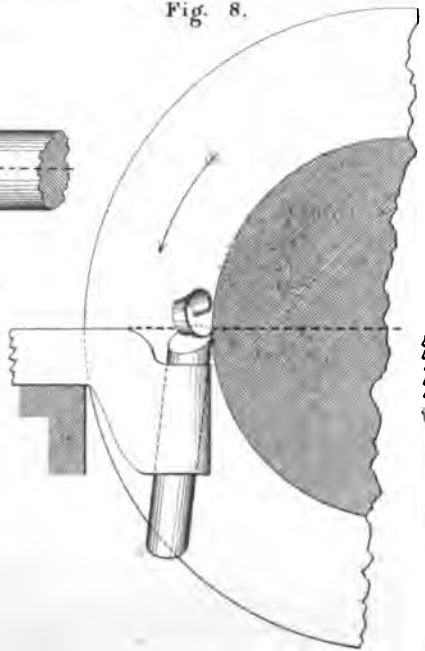
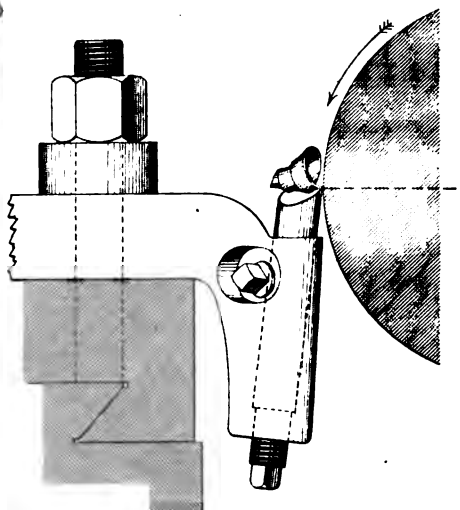


Fig. 9.

Toolholder with Set-screw at bottom for heavy cuts.



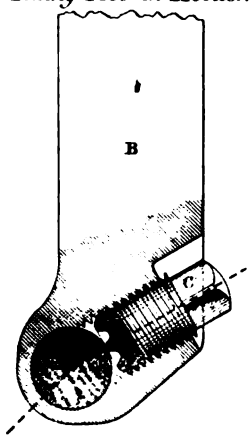
(Proceedings Inst. M.E. 1866. Page 288.)

Scale 1/4 *in.*

IMPROVED TOOL AND HOLDER.

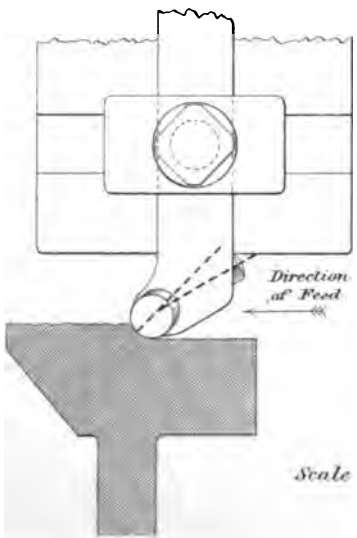
Plate 105.

Fig. 10. *Set-Screw fixing Tool in Holder.*



Scale 1/2

Fig. 11. *Tool planing flat horizontal surface.*

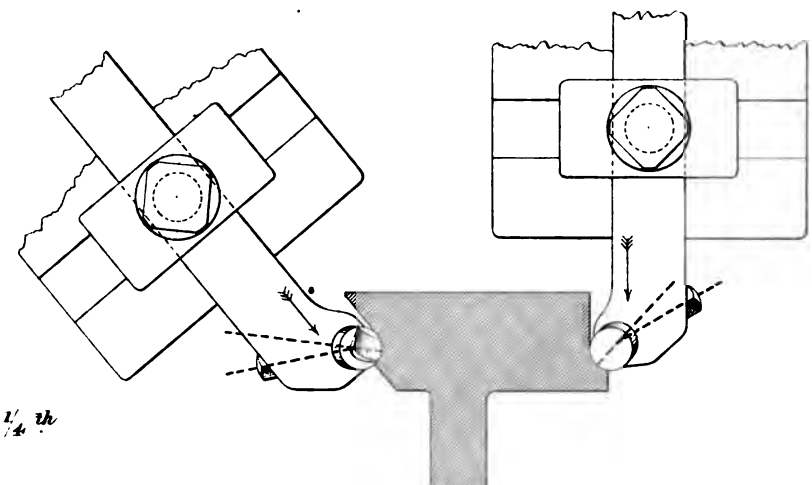


Scale 1/4 th

Tool Down-cutting vertical and inclined surfaces.

Fig. 12.

Fig. 13.



(Proceedings Inst. M.E. 1866. Page 288.) *Scale* 1/4 th

IMPROVED TOOL AND HOLDER. *Plate 106.*

Fig. 14. *Gauge for adjusting Tool in lathe. Scale 1/4 th*

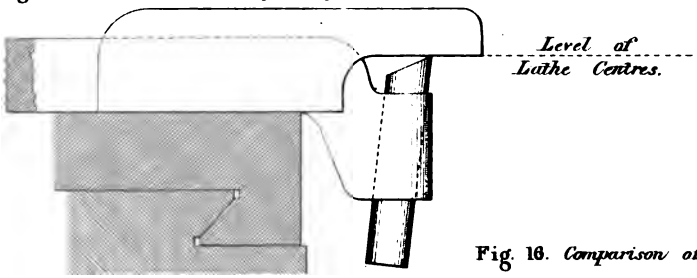


Fig. 15. *Angle Gauge.*
Half full size.

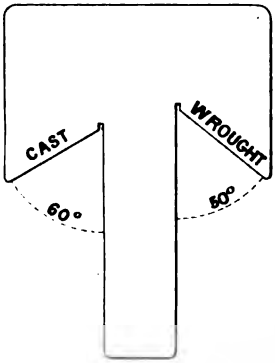


Fig. 16. *Comparison of ordinary diamond-pointed tool and improved round cutter.*
Scale 1/4 th

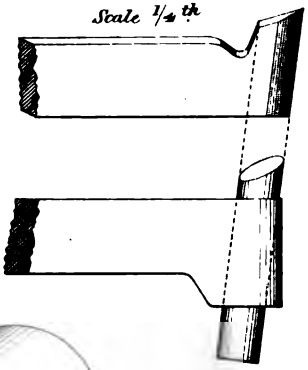


Fig. 17. *Surface produced by improved round cutter.*
Full size.

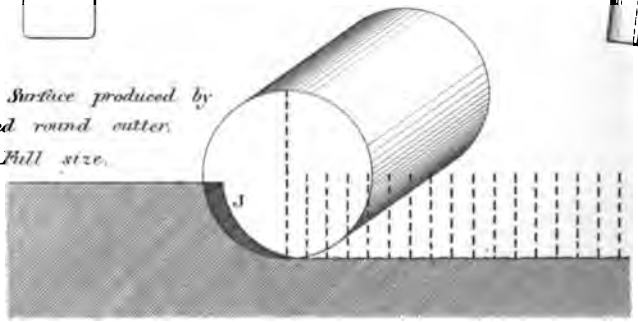
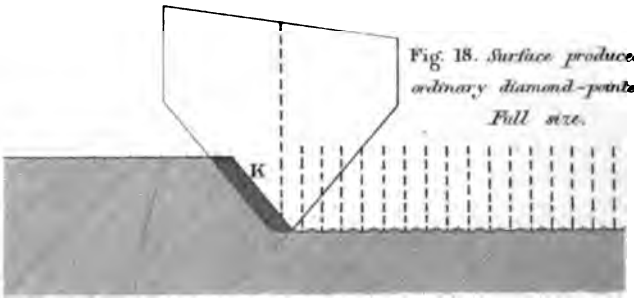


Fig. 18. *Surface produced by ordinary diamond-pointed tool.*
Full size.



(Proceedings Inst. M. E. 1866. Page 288.)

IMPROVED TOOL AND HOLDER.

Grindstone for grinding Tools.

Scale 1/12th

10 5 0 10 20 Inches.

Plate 107.

Fig.19. *Front Elevation.*

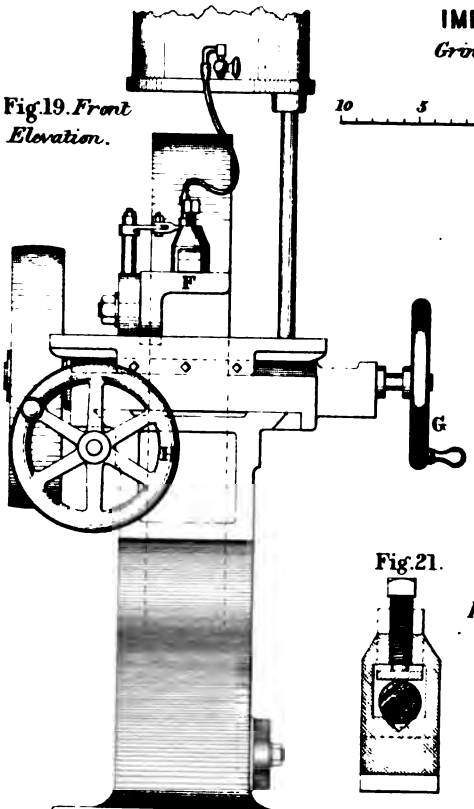


Fig.20. *Side Elevation.*

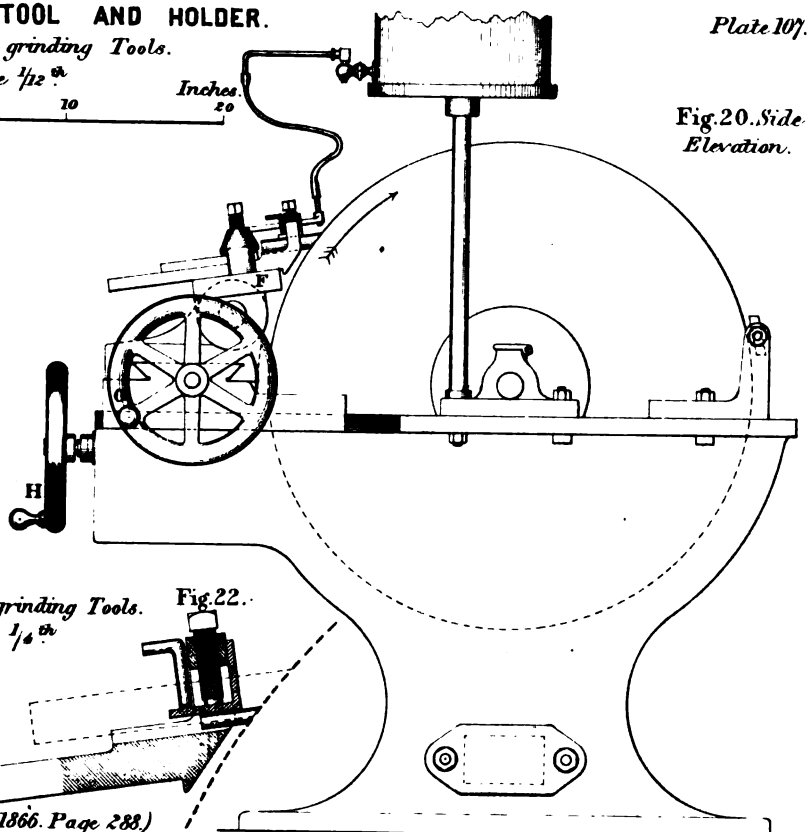
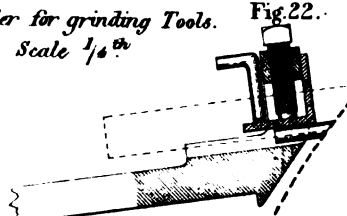


Fig.21.

Holder for grinding Tools.

Scale 1/4th

Fig.22.



(*Proceedings Inst. M.E. 1866. Page 288.*)